A Method for Determining Production Allowances in Prorated Fields

H. D. White, Jr.,* and T. V. Moore*

ABSTRACT

In this paper a method for determining equitable allowable production for wells in prorated fields is presented. The system is based upon the pressure drop in the producing sand observed by the flow of oil in the bore of the well, and is offered as a substitute for the "potential production" determined by open-flow tests. The data required may be taken at low rates of flow, and the results do not depend upon the type of equipment in the well. A numerical illustration is given to show the application of this method.

INTRODUCTION

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ulate may be read directly from the curve. The difference between rock pressure and the bottom-hole pressure at any given production rate is the pressure-drop in the sand required to maintain that production rate. The plot of all productions secured with a given pressure-drop in the sand under widely different wells. The character of the sand, its porosity, permeability, and thickness, the extent to which it is saturated with oil, the physical properties of the oil, and the quantity of free gas which is associated with the oil are the important factors which control the pressure-drop in the sand for a given rate of flow. Porosity and sand thickness, by controlling the area of the pore spaces through which oil may flow, fix the linear velocity which must be established to maintain a given rate of production. Permeability depends upon the character, or average, diameter of these pore spaces and, hence, controls the pressure-gradient which is required to maintain a certain velocity of flow. The physical properties of the oil (especially viscosity) influence pressure losses in a similar manner. Large quantities of free gas flowing in the wells sand, of course, occupy a considerable portion of the space between the sand grains, thus reducing the void space through which oil may flow. This effect probably influences the pressure losses.

The amount of oil underlying a given property is directly proportional to sand thickness, porosity, and saturation. The amount of this oil which can be recovered depends upon permeability, the conditions existing in the reservoir (such as pressure and temperature), and the nature of the oil. As was shown previously, these same factors affect in a comparable manner the rate at which oil can be produced with a given pressure-drop. Thus, the production rate at a given pressure-drop should be a good index of the recoverable oil under a property.

If open-flow rate resulted in the same bottom-hole pressures in all wells in a field, the open-flow production could be used as an index of the productivity of a property. Unfortunately, the bottom-hole pressure at open flow is markedly influenced by the back pressure of the well head and the pressure-drop in the flow string. The back pressure at the well head even under open flow is not zero, but depends upon the size and length of the flow line and the location of the separator. The pressure drop in the flow string depends upon the depth of the well, the size of the tubing or casing through which the oil is produced to the surface, the gas-oil ratio, and the production rate. By changing the design of the flow string and the surface conditions, the bottom-hole pressure at open flow will consequently, the potential production, can be varied over a wide range. Furthermore, if the test covers only a short period, the open-flow may be affected by the history of the well immediately before the test. For these reasons, open-flow tests are not comparable and do not furnish a true measure of the capacity of the various wells to produce oil.

It is obvious that a true measure of the rate at which wells are capable of producing oil must depend on the character of the producing formation and on the conditions under which the flow occurs. The latter factors are controllable, and happens to be in the well. Should be based upon its ultimate production under the conditions imposed by production. It is, therefore, clear that some method of measuring the ability of a well to produce oil which is dependent only upon the nature of the sand and the conditions existing therein, and for which can be obtained values comparable to producing rates of flow. If the new method is to be used in a field already under production, practical considerations require that allowances distributed according to the new method should not differ widely from those distributed under the existing method.

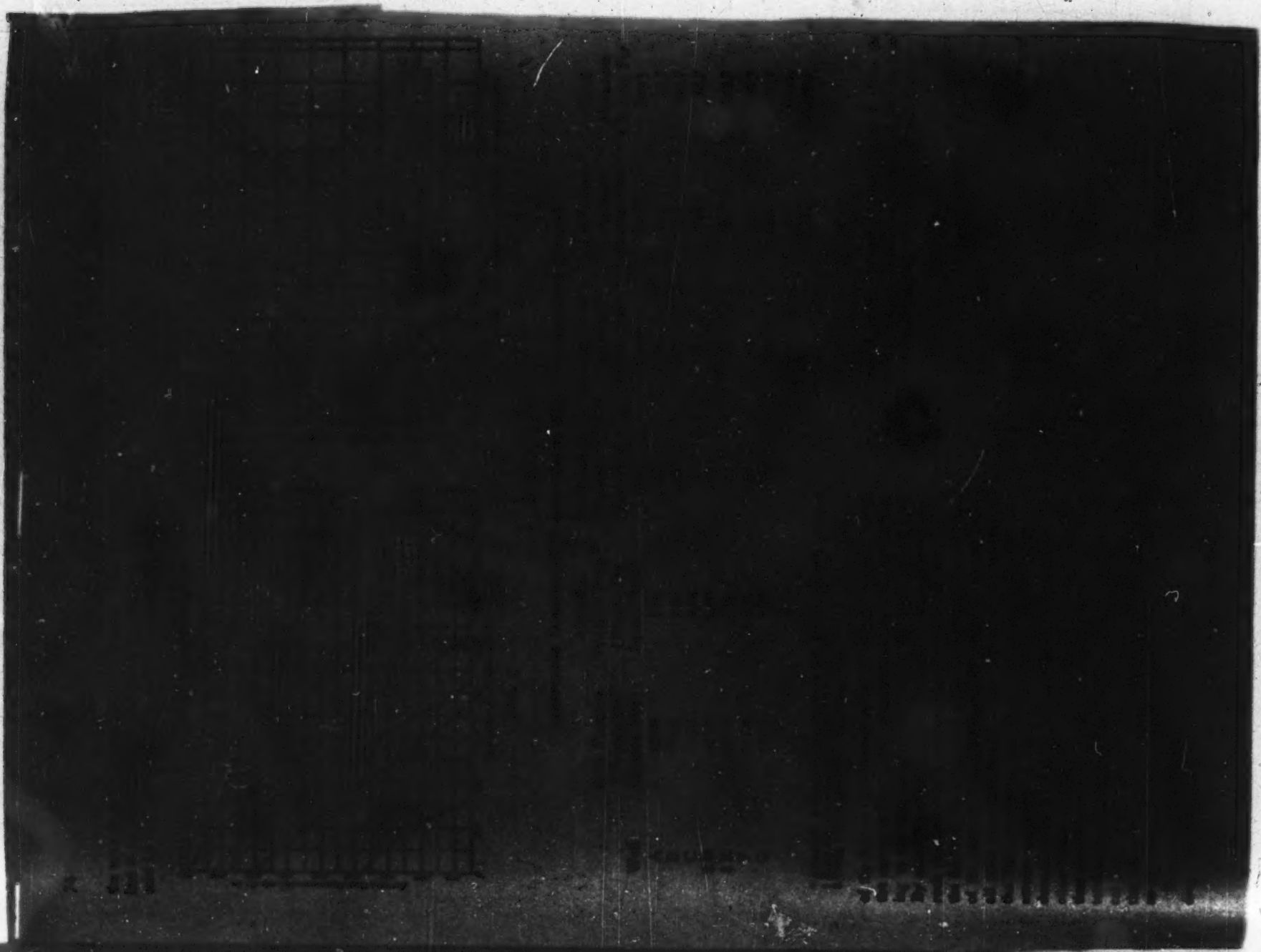
PROPOSED METHOD

The method proposed in this paper is a dual method, based on both acreage and capacity of the individual wells to produce oil. The percentage of the total field production allotted on acreage may be set at any desirable value, but for purposes of illustration it will be assumed arbitrarily that 25 per cent is to be allotted on the acreage basis and 75 per cent on capacity basis. The details of the proposed method are as follows:

The field is divided into units of equal area. Twenty-five per cent of the total production is distributed equally among the various units. The remaining 75 per cent is distributed among the units in proportion to their capacity to produce oil. These capacity allowances for the individual units are determined from the curves showing the relation between bottom-hole pressure and production rate. Inasmuch as the pressure-differential in the sand is the driving force which causes the flow of oil in the well, an equitable method of distribution would allow all operators to produce oil under a driving force which is a certain percentage of total driving force available. Hence, for any given well, the allowance is the rate at which it can produce oil when the pressure-drop in the formation is a definite percentage of the rock pressure. This percentage is fixed for the entire field. On units having more than one well, the capacity allowance for the unit is the average of the capacity allowances of the various wells thereon. For units having more than one well, the allowance may be taken from a single well or distributed among the various wells in the unit, depending upon local conditions; but in no case shall the sum of the production from the various wells exceed the unit allowance. The percentage of the rock pressure used in determining the capacity allowances is so adjusted that the sum of the unit capacity allowances will be 75 per cent of the total production which it is desired to take from the field. The determination of the value of the percentage of rock pressure which will fix the total production at any required value may be accomplished by simple interpolation. A procedure which may be followed in this determination is outlined in the numerical illustration given below.

Numerical Illustration

In order to illustrate more clearly the application of the proposed system, the following example of its application to an hypothetical field is given. The data required to determine the relationship between bottom-hole pressure and production rate for each of the open-flow tests for the wells in the hypothetical field have already been taken as seven wells in West Texas. The curves showing these relationships are presented in Fig. 2. Let us assume that these seven wells constitute an entire field whose total production is to be 1,000 bbl. per day. Assume wells "D" and "E" to be in



If the outlet of the field is to be 1,000 bbl. per day, 770 bbl. are to be distributed in proportion to the average well potential. The allowance of each unit which is based on potential is the ratio of the average unit potential to the total potential, multiplied by the daily allowance which is to be distributed in proportion to the potential. Table 3 is a summary of the calculations involved in the distribution of these allowances upon the basis of the open-flow test.

TABLE 3

Allowances Distributed in Accordance with Method Using Open-Flow Test

Unit	Ratio Average Unit Potential to Total Potential	Unit Allowance on Potential (Barrels Per Day)	Unit Allowance on Average (Barrels Per Day)	Total Allowance (Barrels Per Day)
A	0.0705	53	41.7	94.7
B	0.0556	43	41.7	84.7
C	0.0539	42	41.7	83.7
D-E	0.1705	131	41.7	172.7
F	0.1065	79	41.7	120.7
G	0.1430	110	41.7	151.7
		770	250.2	1,020.2

In Table 4 is presented a comparison of the allowances by the various units as calculated on the basis of the open-flow tests and on the basis of potential heads at the time the outputs of 1,000 bbl. per day and 2,000 bbl. per day

TABLE 4

Comparison of Allowances

Unit	Open-Flow Test	Static Head Test	Open-Flow Test	Static Head Test
A	94.7			
B				
C				
D-E				
F				
G				

developed which may be run in the wells on wire lines. These instruments are, in general, of two types: those recording pressures continuously, in which a chart is moved by means of clock-work; and those in which maximum pressures only are registered. The former type have the great advantage of furnishing a record of bottom-hole pressures throughout the entire period of the test. However, because of the limitation imposed by the size of the clock-work, these instruments are usually too large to be run in wells equipped with small tubing. Successful maximum registering instruments have been built with outside dimensions as small as 1¼ in. These instruments, however, must be run each time the conditions in the well have changed, if the effect of pressure upon these conditions is to be studied. The development of such instruments is being carried forward, and while the case favors devices which incorporate the advantages of both types may be available.

Under favorable conditions, two runs per day under their determinations of bottom-hole pressure by a recording gage. If runs are available for a small and suppose the [illegible] through which these tests are run, this [illegible] runs who run the instruments from the [illegible] What can be done in these circumstances [illegible] run the tubing outside. The number of [illegible]

Disadvantages of Proposed System

However, in this proposed system there are certain [illegible] disadvantages:

1. [illegible]

2. [illegible]

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Bottom-Hole Pressures

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DETERMINATION of pressures existing within oil wells is of increasing importance to petroleum production engineers. The value of such measurements has been particularly emphasized by the publication of bottom-hole pressure data in the control of production in Yates Pool and by the attempts which are now being made to develop data which can be used for similar purposes in East Texas.

Application of Pressure Measurements

Measurements of this type promise to be of the greatest practical value as a means for determining the conditions existing within a producing formation. Although only a few of the possible applications have as yet been investigated and developed, it has been shown that considerable of great value can be obtained through measurements of bottom-hole pressures. The work which has been done emphasizes even more important future engineering developments. Three general classes of measurements of pressures within oil wells may be mentioned:

A. Measurements of pressures at the bottom of an oil well while it is shut down; that is, the equilibrium pressure of the producing formation when no oil is being withdrawn.

Measurements of this type may be applied to follow the rate of depletion of an oil field. Methods for doing this have been developed and described by the Texas Pool Engineering Committee,[1] and are now being applied in East Texas.[2] Of course, an intensive application of bottom-hole pressure data for this purpose involves the study of rate of water encroachment, and of solubility of dissolved gases. In conjunction with these factors, it is possible that data on bottom-hole pressures will lead to a very accurate picture of formation conditions. From values derived by engineering calculations, shut-down bottom-hole pressures are of great utility in studying rate of depletion of a field, and are a necessary part of any scheme of control which is based upon considerations of reservoir energy.

B. Measurements of bottom-hole pressures while wells are producing.

Measurements of this type, in conjunction with measurements of density and viscosity, make possible a direct determination of the effective permeability of a producing formation.[3] This has been proposed as the basis for an equitable schedule for operation and is determining the potential production of wells.[4] For many detailed

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Appendix B of the present report is in the form of [illegible] by research engineers of the Texas Pool Engineering Committee. These reports are [illegible] Pool Engineering Committee, also [illegible] and W. H. Wood.

...data there are now available are extremely limited. This application can be made, but a direct question to [illegible] engineering deliberations.

...measurements of pressures throughout the length of a well [illegible] data will be obtained from such measurements. For example, measurements of pressures throughout the length of the casing of a well which is producing by natural flow or gas lift will develop data for a most accurate interpretation of the forces which [illegible] have possible. This will lead directly to improved drawing bits, and to more economical application of gas-lift methods.

Methods of Measuring Pressures Within Wells

The methods which are available for measuring pressures existing within wells have been thoroughly described by Millikan and Sidwell.[5] Besides the methods which have been used are:

A. Measuring hydrostatic pressure by displacing fluid from the casing with gas.

The gas pressure at the surface, plus a correction for the weight of the gas column, is equal to the pressure existing at the bottom of the casing. This is the most accurate method available, but is subject to certain disadvantages. The most important of these is the high cost and large size of the compressor equipment which must be used. In the long shut-in periods necessary for making measurements, and in the fact that such tests must necessarily be shut down while measurements are being made.

B. Bombs sealed with check valves and designed to bring to the surface samples under the pressure existing within a well have been widely used, particularly in West Texas.

Such bombs are very simple, but do not give accurate results. The main reason for this inaccuracy lies in the frequent disappearance of check valves; any simple valve which can be designed for this purpose will result in low readings of well pressure when the method is employed. Some inaccuracy is also induced by the volume of the casing head for determining pressures, by leaking of valves and connections, and by more or less complete [illegible] which are mixed with solubility of air and gas.

C. The bottom-hole recording gage is the most accurate and of the present time are known which other methods employing a recording gage, which remains in the well.

The check valves mentioned above will almost only one reading of a well. This gave additional gage [illegible] chart of pressures, and are controlled either by clock-work or other mechanism, to make possible a series of pressure readings at different points within the well on a single trip. Very valuable results have been obtained by the use of gage

sure gauges of this type, but they are, unfortunately and unavoidably, somewhat inaccurate. This inaccuracy results entirely from the impossibility of building an accurate gauge within the very small space which is available in an instrument which can be run through the tubing of an oil well. For practical purposes, the outside diameter of such an instrument cannot be more than two inches. A smaller outside diameter is highly desirable, since a bomb having a two-inch outside diameter cannot be satisfactorily used in a well while it is producing, because the flow of fluid will make it difficult to lower it through the tubing, and since the gauge will interfere with the flow through the tubing, and the pressures measured will be different from those existing before the gauge was placed in position. This limitation of size of the gauge elements, combined with the necessity for great ruggedness, makes it impossible to develop an instrument of this type which will read well pressures accurately. The scales are necessarily so small that precise reading is impossible, and the construction of the moving parts is such as to deprive the gauges of any great delicacy. Although but few figures are available to support such a statement, it is extremely likely that none of the pressures measured with bombs of this type, even when controlled by frequent calibration of the gauges, are accurate within five per cent.

D. *In fields where the bottom-hole pressure is sufficient to support a solid fluid column to the surface, it has been found possible to calculate shut-in bottom-hole pressures with a considerable degree of precision from the surface pressure and the average specific gravity of the fluid column.* A similar calculation can be applied in fields of lower pressure, provided the height of the standing fluid column can be accurately determined. This method is particularly applicable in East Texas and affords a simple and rapid means of following changes in bottom-hole pressure. However, the calculation cannot be made until the average specific gravity of the fluid column has been accurately determined by actual measurement of bottom-hole pressure. Further, the specific gravity will change as the average bottom-hole pressure of a field declines, and it will therefore be necessary to re-determine the constants at frequent intervals in order to insure the validity of the calculated values. Hence calculation, although its utility has been proven, is entirely dependent upon the use of measuring devices.

The new apparatus, which is described below is designed to eliminate as many as possible of the difficulties which have been experienced with other types of equipment for measurement of oil-well pressures. The requirements which it was intended to meet are:

a. The instrument should be capable of reading pressures at any point within the well, either flowing or shut-in, with a high degree of precision.

b. Readings should be rapid; that is, it should be possible to take a large number of readings, and to check the readings, on a single trip into the well.

To meet the requirements of precise reading, and to avoid the necessity of putting delicate and expensive measuring instruments into the well, it was decided to build an apparatus which would measure pressures by the first method listed above; that is, by balancing the pressure of a gas column against the well pressure at the point of measurement. To eliminate the necessity for heavy and expensive compressor equipment, and to make it possible to read pressures at any point of the tubing of the well, it was decided to use compressed gas out of cylinders for the measurement, and to introduce it into the well through an

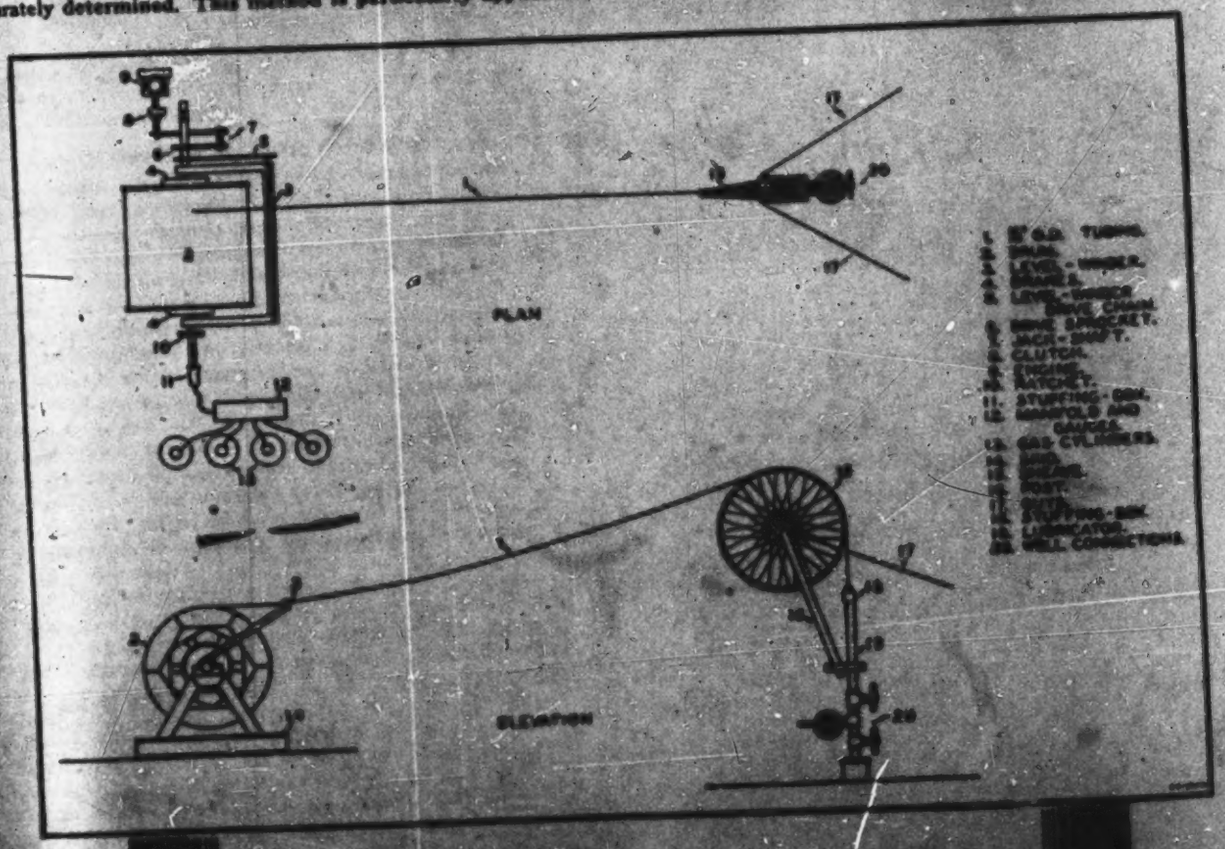


FIGURE 1—Diagram of typical bottom-hole pressure apparatus.



FIGURE 2—General view of apparatus mounted on trailer. Standing at the rear, this view shows the small gasoline engine used for hoisting the tubing upon which the tubing is rolled, the low-capacity manifold and gauges, and four cylinders of hydrogen mounted in a rack.

extra string of small tubing. For economy of compressed gas, and to facilitate the handling of equipment, very small tubing was used.

General Features of "Gulf" Apparatus

The apparatus, as finally designed to meet these requirements, consist essentially of a continuous string of tubing, one-eighth inch outside diameter and one-sixteenth inch inside diameter, long enough to reach to the bottom of the wells measured, and handled into and out of the well by a special hoisting drum which is made of large diameter to avoid destructive bending of the small tubing. The bottom end of this tubing string carries a set of check valves, which are not essential to the operation of the apparatus, but which are carried as an added protection against the admission of fluid to the small tubing. In addition, the bottom end carries a pressure-tight well for a maximum registering thermometer. At the surface, the tubing is connected to the pressure gauge, and to cylinders of hydrogen gas which supply the pressure for equalizing the pressure within the well.

The method of making measurements is extremely simple and rapid. The tubing is run to the desired depth, and hydrogen is admitted from the cylinders. Hydrogen pressure is built up until it is considerably higher than the expected reading. The gas supply is then shut off, excess gas escapes from the open bottom end of the tubing, and the equilibrium pressure is read at the surface from the pressure gauge. Obviously, the only correction which need be applied to this reading is the weight of the hydrogen column within the tube, since the readings are made with a static gas column, and are not influenced by any friction factors. As soon as a reading is taken, hydrogen is again admitted, and the procedure repeated to obtain a check reading. In the work which [illegible]

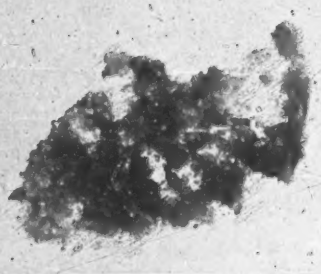




FIGURE 4—Stuffing-box end of tubing hoist shaft. 1. End of drum. 2. Brake drum. 3. Support for head-cylinder. 4. Bracket. 5. Shaft. 6. High-pressure stuffing-box.

apparatus, it has been found easy to check bottom-hole pressure readings in East Texas within one or two pounds per square inch on repeated readings.

Details of Construction

The essential features of the construction of the apparatus are briefly described below. The equipment has been loaded upon a trailer, as shown in the illustration. So large a truck is not really essential, and was used merely to provide adequate space. The weight of the entire apparatus, including the four cylinders of gas and the gasoline engine which is used to drive the hoist, is less than 3000 pounds.

A. *Tubing.* The tubing string is of seamless steel, one-eighth inch outside diameter and one-thirteenth inch inside diameter, and 4000 feet in length. The tubing was produced in lengths of 40 to 50 feet, and was fusion welded into a continuous length at the plant of Howard Smith Company, under the supervision of Mr. Hillman D. Wilson, engineer for Howard Smith Company. The outside of each weld was filed smooth, and the weld was then subjected to test under a tensile load of 300 pounds. In view of the fact that the total weight of the 4000-foot string of tubing is only 125 pounds, it was felt that this test load was adequate. The welding required exceptional care and skill, and much credit is due to Mr. Wilson and Howard Smith Company for carrying out this work. In view of the difficulty of welding, and the possible danger of breakage at the welds, Gulf engineers plan to substitute a string of tubing of the same dimensions, but made of brass or bronze of high tensile strength. Tubing of this type can be obtained in very long lengths, and the number of joints in the tubing string correspondingly reduced.

B. *Bottom End.* The bottom end of the string of tubing is brazed into a short one-fourth inch pipe nipple. This screws into the bottom end, a sinker bar, a weight of 10 or 15 pounds. The bottom end carries a pressure-tight cell for a maximum registering thermometer, and a pair of three-thirtieths inch ball check valves. These valves shut off the bottom end of the tubing string, and are designed to make it possible to run the apparatus into a well without carrying gas pressure on the tubing. It is very important that fluid should be completely excluded from the steel tubing; the check valves are not absolutely certain, and for this reason it has been found advisable to carry gas pressure into the tubing while it is being run into the well, as an added precaution against the admission of fluid. The present bottom end has an outside diameter of 1¼ inch, but plans have been made for one having an outside diameter of three-fourths of an inch, which may be used inside one-inch or 1¼ inch tubing.

C. *Tubing hoist.* The 4000-foot length of tubing is coiled in a single layer upon a drum four feet in diameter and four feet long. The drum is made of wood, which is covered with heavy duck, treated with airplane dope. The drum is carried by angle iron spokes on a 2 5/16-inch shaft. On each end of the drum is mounted a heavy automobile brake drum and brake. The shaft also carries a heavy ratchet and pawl, which are engaged in pulling the tubing from the well, and prevent dropping the tubing, if anything goes wrong with the hoisting equipment. The shaft also carries a "level-winding" mechanism which guides the tubing onto the drum. A drive sprocket is attached to the shaft with a breaking-pin, which is proportioned to shear off if the load on the tubing exceeds 250 pounds. This is a safety precaution, to prevent pulling the tubing in two if it should catch. From the drive sprocket, drive chains pass through a jack-shaft and clutch to a five horsepower gasoline engine which provides power for hoisting. Hoisting power could equally well be provided by a power take-off on the truck; but the engine was used for greater portability and flexibility. All of the



FIGURE 5—Plan of tubing, showing two guide rod rod view. Apparatus actual size.



FIGURE 6.—Lubricator, swivel elbow, and valve for one of the gauges.

mechanism, including the engine, is mounted on

Operator at well head. From the drum of the tubing which is placed not less than 75 or 100 feet from the the tubing passes over a sheave four feet in diameter mounted over the casing head. The sheave is of ht construction, having a deeply grooved steel rim carried on a hub and axis from the front wheel otorcycle on motorcycle spokes, which were cut o the necessary length by welding. The sheave is d from a section of pipe which is mounted as a r on the casing head, and is also guyed to hold ately in position. The tubing passes from the through a stuffing box on the top of the lubricator Valves on the Christmas-tree are used in lubricat- bottom end into the well tubing.

connections. The upper end of the one-eighth-inch brazed into a one-fourth-inch pipe nipple, which is with a high pressure union to a nipple which is nto the shaft of the tubing hoist. A hole is drilled e axis of this shaft to one end, on which is a high-pressure stuffing box of special design. ffing box, which works on the principle of packing ras against grease carried in a ground joint and packing gland, has been found to be perfectly ainst from 1500 to 1800 pounds per square inch sure. From the stuffing box connection is made as manifold.

manifold. The gas manifold is made up of one- ch hydraulic pipe and one-fourth-inch—3000-pounds needle valves. The main gauge, which is used for urement of well pressures, is a 12-inch—3000 pound ydraulic gauge. This gauge has been fitted with scale reading directly to 10 pounds per square permitting accurate estimation to one or two er square inch, since each 10 pound division of the a length of more than one-eighth of an inch. The of course, periodically calibrated against a dead ester, and the manifold also carries connection for auge, with which the calibration of the working periodically checked. The manifold carries in- gauges and valves for four hydrogen cylinders.

Publishing Company Publication

Correction for Weight of Gas Column

When measurements of well pressures are made with this apparatus, it is necessary to add to the pressure measured by the gauge a correction for the weight of the column of gas within the small tubing. This correction is of course small, and is in fact less than the errors which are present in measurements made by other methods. However, the correction for the weight of the gas column is very simply made, and is necessary for the accurate determination of well pressures.

The exact bottom-hole pressure may be calculated from the measured values by the use of the following formula:

$$P_b = P_m + \left[\left(\frac{.00559}{144}\right)(D)\left(\frac{P_b + P_m}{2 \times 14.7}\right)\left(\frac{460}{460+T}\right)\right]$$

or, in simplified form

$$P_b = P_m + \left[\left(.00007\right)(D)\left(\frac{P_b + P_m}{460+T}\right)\right]$$

where

P_b = the actual pressure at the bottom of the string of ¼" tubing, in pounds / sq. in., absolute.

P_m = the pressure measured by the gauge at the surface, pounds / sq. in., absolute.

D = the depth at which the measurement was made, in feet.

T = the average temperature of the gas column, in degrees Fahrenheit.

The constant, .00559, is the weight of one cubic foot of hydrogen gas at 0° F., under a pressure of 14.7 pounds per square inch absolute.

This complete formula need seldom be used, since it provides a correction far more precise than that obtainable by measurement. The only case in which the correction need be calculated by this complete formula is where the pressures measured are extremely low, and where the highest precision is required.

For all ordinary purposes, a sufficiently precise approximation can be expressed in a far similar formula, as follows:

$$P_b = P_m \left[\left(.001214\right)(D)\left(\frac{P_m}{460+T}\right)\right]$$

This approximation is made by calculating the pressure of the gas within the string of one-eighth-inch tubing, as equal to the pressure measured at the surface, rather than as an average between the measured pressure and the

actual pressure at the bottom of the string. The error induced by this assumption is entirely negligible. It is also possible to make a valid calculation on the basis of a somewhat rough estimation of temperature; for example, an error of 50° F. in temperature of the gas column would result in an error of only one pound per square inch in a measurement of bottom-hole pressures under conditions at present prevailing in East Texas.

Auxiliary Equipment

The design of the apparatus is such as to make possible the use of auxiliary devices for obtaining additional information on well conditions.

Although no work has as yet been done in the field along these lines, apparatus has been developed for securing samples of well fluids under the exact conditions existing within the well, and for a very accurate determination of the specific gravity of the fluid at any point within the well. Both of these devices will make it possible to secure valuable engineering data.

Summary

Use of the Gulf bottom-hole pressure apparatus in the East Texas field has shown it to be extremely accurate and satisfactory. The few difficulties which have been experienced have been readily overcome, and are not at all basic.



FIGURE 7—Level Winder.

The great advantages of the apparatus lie in the precision of the measurements, in the fact that no intricate or expensive parts are placed inside of the wells, and in the possibility of making accurate readings at any point within a well, equipped with tubing of any size, whether shut-down or flowing, and of making any desired number of such measurements on a single trip into the well.

It is not believed that the apparatus should be applied for a day-by-day checking up of bottom-hole pressures within a field. In almost any area where frequent measurement of pressures is necessary, it is possible to develop some simple means for routine check-up, provided accurate equipment is available for a periodical calibration of the routine method. For example, tests made with the apparatus described in this paper have shown that bottom-hole pressures in East Texas can be very precisely determined from the top-hole pressure and the weight of the column of fluid within the tubing. Of course, precise measurement of bottom-hole pressures are necessary for the development of such a method, since only thus can the weight of the fluid column be accurately determined. For the East Texas field it has been found that a periodical check-up and re-determination of the weight of the fluid column by the use of the precision apparatus will make possible a very accurate and inexpensive determination of bottom-hole pressures from pressures at the tops of the tubing strings.

The apparatus described makes simple and practical measurements which have not hitherto been available, and is expected to develop data which will prove of great value to the petroleum production engineer.

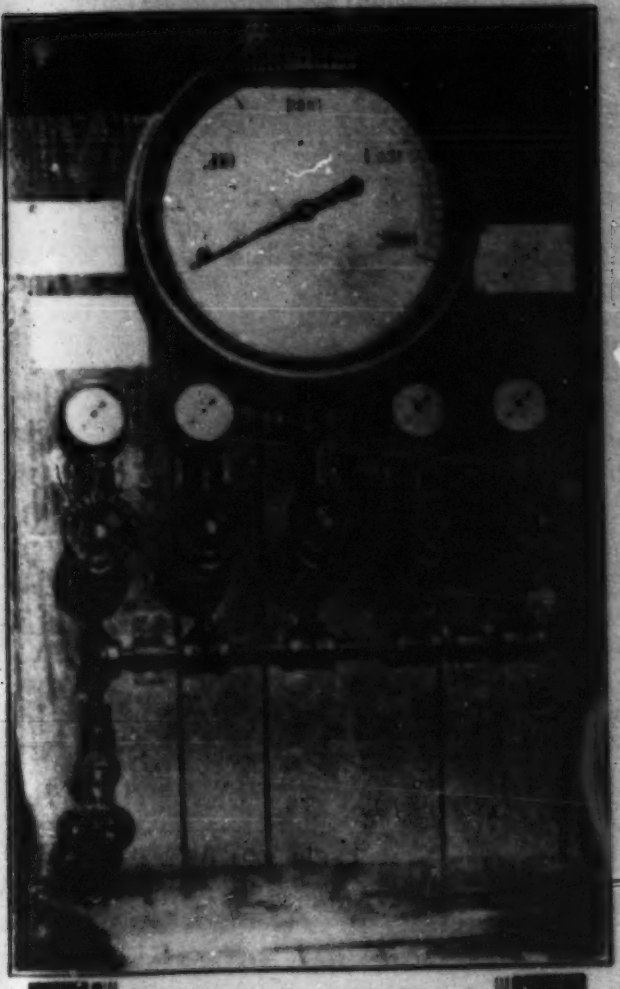


FIGURE 8—Gas Manifold and Gauges.

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Subsurface Pressures in Oil Wells and Their Field of Application

by R. O. Kaveney,* Tulsa, Okla.

(New York Meeting, October, 1919)

[illegible] during the past year in the study of [illegible] relevant to its early development. [illegible] value commercially obtained [illegible] is available that [illegible] as 14 or 17 years ago. There is [illegible] of actual subsurface tests made by [illegible] in 1918 and 1919.[1] These [illegible] made on wells produced [illegible] of the work led to the [illegible] which is reputed to have [illegible] From this time on to 1927 a [illegible] were made with mixed [illegible] but probably not until 1927 was [illegible] obtained in this subject.

[illegible] four years ago was [illegible] in this country within for the [illegible] and importance of subsurface pres- [illegible] thought to have been the first to present data [illegible] through the use of a specially [illegible] apparatus capable of repeated, and [illegible] pressure measurements were obtained and, in [illegible] represented a progressive step in the right direction. [illegible] the past few years, many noteworthy improvements [illegible] and production of subsurface pressure instruments [illegible] Because of the magnitude of this task, [illegible] who pioneered this work. They should feel a [illegible] in the thought that their efforts have paved the [illegible] the construction of this most valuable study.

At the present time more than a dozen companies are operating sub- [illegible] pressure instruments in the Mid-Continent field. Engineers in

* Production Engineer, Roxanah Oil Co.

[1] First published by J. T. Hayward, Extension Consultant Oil Fields, Ltd. [illegible] C. Miller and R. R. Stephenson, Measurement of Original Pressure, Tem- [illegible] and Casing Heads in Oil Wells. Trans. A.I.M.E., (1920-21) 69, Petr. Dev. and Tech., 113.

[redacted]

[illegible]

Rules and Explanations

[illegible] (A) Wells in which the head of oil is maintained purely through hydrostatic pressure. Further, for the sake of convenience, let us call such a well, whose pressure is even then sufficient to maintain a solid column of fluid to the top of the hole, an artesian well, and one whose pressure will maintain only a partial column, a semi-artesian well. (B) All wells not included in A and in which flow gas exists in the formation.

A

1. Bottom-hole flowing pressure cannot be accurately calculated on either an artesian or a semi-artesian well due to continuously changing temperature and to the liberation of gas from solution.

2. The calculation of bottom-hole static pressure for semi-artesian wells is impractical due to the necessity for making allowances observations of fluid level each time a calculation is desired.

3. By taking a few simple precautions the bottom-hole static pressure in an artesian well can be easily calculated from the following formula:

$$P = D \times 0.4335 \times G + p$$

Where P is [illegible] pressure,
D is depth of desired pressure,
G is flow column specific gravity of oil,
p is surface pressure,
0.4335 (weight per foot of water).

The specific gravity of the oil within the flow column may be readily obtained from one simple static gradient test with a pressure bomb. The calculation is simply the ratio of the pressure drop within the flow column per unit of length to the pressure drop or weight of an equal length column of water. An example of this calculation is shown in curve 1, Fig. 1.

4. To obtain accurate results, care must be taken regarding the temperature of the oil in the flow column. Preferably, no tests or observations should be made less than 24 hr. after the well has been flowed, thus giving the oil in the column a chance to reach static earth temperature.

5. Precaution also must be taken in bleeding off the small pocket of gas which accumulates at the top of the hole. This must be done slowly so as not to decrease the pressure sufficiently to cause the gas to come out of solution and produce a frothy condition of the oil at the top of the flow column.

Wells in the East Texas field furnish a striking example of the application of this method of calculating bottom-hole or subsurface pressures. By closely observing the above directions, results under 0.5 per cent of error should be obtained.

B

1. To calculate static or shut-in pressure on wells of this type, in which free gas exists at the bottom of the hole, is usually impossible as conditions are virtually the same as in a "sandertesian well." Occasionally in wells with very high gas-oil ratio the formation pressure may be closely calculated due to the fact that on closing the well in pressure is built up so rapidly that no fluid head is allowed to accumulate. An illustration of this instance is shown in curve 1 of Fig. 5.

2. Unless a well of this type is tubed, the bottom-hole flowing pressure can in no way be reliably calculated. Acknowledgment is made to those men who have studied and are studying the derivation of formulas for calculating pressure drop in flow columns, but as yet it is believed the work is still in the experimental stage.

3. If it is certain that the fluid within the static column is dispersed to the bottom of the tubing while the well is flowing, the bottom-hole pressure, or more correctly speaking, the pressure at the bottom of the tubing can be accurately calculated by either of the following formulas:

$$\text{Log}_{10} P = \frac{S \times S}{\text{[illegible]} \times T} + \text{Log}_{10} p.^1$$

Where P is bottom-hole pressure, absolute.

S is depth of tubing inlet in feet.
S is specific gravity of gas.
T is absolute temperature of gas (° F. + 460).
p is surface pressure, absolute.

$$[P = p(e^{\text{[illegible]}} - 1) + p.^2$$

Where P is bottom-hole pressure, absolute.

p is surface pressure, absolute.
e is base of Nap. log (2.71828).
G is specific gravity of gas.
L is length of producing string.

(An average temperature of 60° F. is assumed.)

These formulas were derived for the purpose of calculating the weight of a static column of gas. A practical application of each of these formulas is shown in Fig. 5. The results are seen to check very closely with the pressure obtained at the corresponding depth from the pressure bomb.

4. It is impossible to mention here all of the cases where bottom-hole pressures on this type of well can or cannot be calculated from surface pressure. The greatest difficulty is probably encountered in making sure that the static column is completely filled with gas. Frequently, bridges of collected rotary mud or slugs of more or less permanent oil froth may be entrapped in the column. Also the position of the bottom of the tubing with respect to the point at which all is entering the hole is of great importance. Undoubtedly, many other features enter into the problem and extreme precaution and good judgment must be exercised to insure correct application and results.

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[1] Derived by Marion Dice, Gasoil Petroleum Corporation of California.
[2] Derived by Reese and Rawlins. U.S. Bur. Mines, *Rept. of Investigations* No. 2000, 8.

Subsurface Tests

Subsurface pressure tests in general may be divided into two classes, static tests and flowing tests. In either case pressure may be obtained at any point within the flow column to which a pressure bomb can be lowered, thus giving information from which curves, or pressure gradients, can be plotted; see Fig. 1, where curve 1 is the static pressure gradient, curve 2 is the flowing pressure gradient and curve 3 is obtained by plotting bottom-hole pressure against rate of production of the well during the test. This constitutes all the information in regard to pressure that is directly obtained in making a subsurface test. If desired, the bottom-hole temperature may be easily obtained by attaching a maximum recording thermometer to the bomb. A few pressure bombs are designed in such a manner as to give a continuous temperature record.

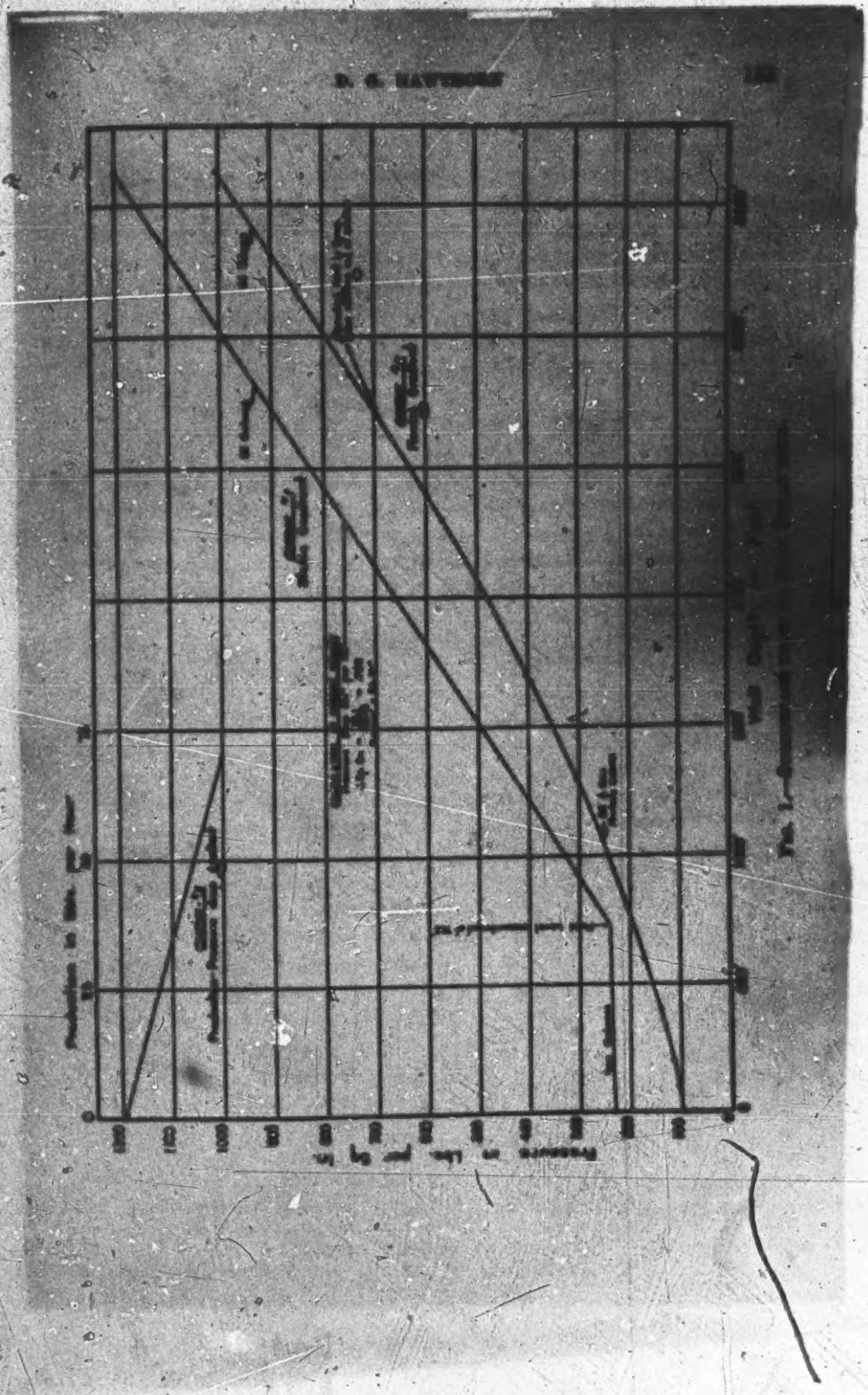
The importance of these data, simply through their obvious meagerness, has been greatly underestimated. The question is still frequently asked, "What information can bottom-hole pressures render other than total formation or reservoir pressures?" The value of subsurface pressure data, like many other classes of field information, lies not in the data but in the interpretation and application. A knowledge of subsurface pressures has long been the "missing link" in the chain of study relative to oil and gas flow in earth reservoirs and well bores. This information is now available and, as our fund of knowledge grows, subsurface pressures are destined to become the "nucleus" around which much practical and theoretical work will be centered and from which valuable interpretations will be made both in the field and in the laboratory.

Use and Application of Subsurface Pressures

The practical application of subsurface pressures embodies a great variety of problems. So extensive and complicated has the study of their application become that it is necessary, in order to obtain a comprehensive impression, to divide the subject into its component parts. The subject naturally separates itself into two main divisions: (1) the application to oil reservoirs and (2) the application to individual wells. The following discussions will be divided accordingly.

Application to Oil Reservoirs

Equitable proration and unitization during the past few years have been two of the foremost problems confronting the industry. In turn, both have presented and made necessary the solution of difficult problems of evaluation. In attacking these problems geologists and engineers have frequently found themselves with but a few facts and figures upon which to proceed. Subsurface pressures offer a new line of attack and furnish valuable and concrete information relative to existing conditions in reservoirs.



Formation Characteristic

Subsurface pressure and, more specifically, bottom-hole flowing and static pressures, possess valuable information relative to conditions and characteristics existing in the reservoir, information which heretofore could only be secured in part by laboratory analysis. One of the most valuable determinations that bottom-hole pressures have to offer is the so-called "productivity factor." This factor may be defined as "a measure of the capacity of a well to produce." More specifically, it is the rate at which oil is produced from a well per unit of differential pressure.

$$\text{Productivity Factor} = \frac{\text{Rate of Production}}{\text{Differential Pressure}}$$

As the value of this productivity factor directly depends on the [illegible] factors as permeability, i. e., porosity, saturation, texture, [illegible] its form, etc., it is also a measure of the permeability of the [illegible]. However, in order to render this measure of [illegible] of use it is necessary to reduce it to a work-[illegible] basis.

$$\text{Permeability Factor} = \frac{\text{Productivity Factor}}{\text{Fluid Penetration} \times \text{E}}$$

[illegible] depending on the diameter of the hole. Thus the [illegible] factor may be defined as the quality of the reservoir [illegible] viscosity of a fluid to produce oil per unit of differential [illegible] for each of [illegible] penetrated. This furnishes a prac-[illegible] upon which investigation of formation characteristics may [illegible]

[illegible] of [illegible] Texas in the East Texas field. The [illegible] factor has been [illegible] against sand penetration for wells [illegible] parts of the field. [illegible] may be called a permeability chart [illegible] the slope of the curves indicates the relative factor of [illegible] for the [illegible] districts. This factor is computed and [illegible] the chart. Considering the limited data at hand it is felt desir-[illegible] to make too literal an interpretation. Nevertheless, it is thought to [illegible] of actual conditions and is cited to illustrate a method of [illegible] reservoir characteristics to individual wells, leases or even [illegible] pool.

Ultimate Recovery

Attempts have been made to predict ultimate recovery from reservoirs by plotting cumulative percentages against reservoir pressure and extend-

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[illegible] and T. P. Meyer, A Method for Determining Productive Elements [illegible] Petroleum Reservoirs, Bull. 307, U.

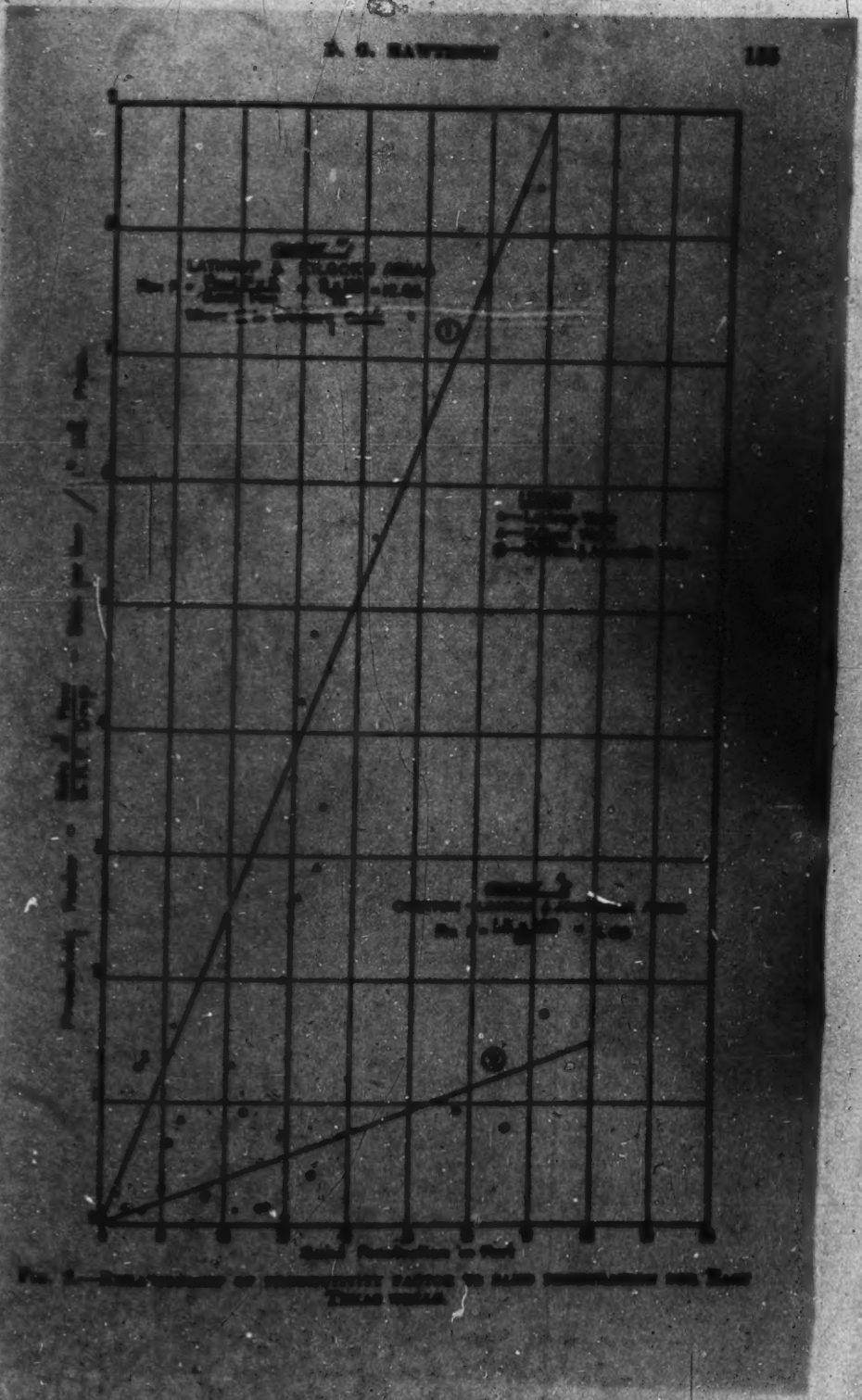




FIG. 2.—RELATIONSHIP BETWEEN PRESSURE AND PRODUCTION OF THE EAST TEXAS FIELD. CONTINUED ON—2000-FT. SANDS.

Data supplied through the cooperation of the following companies: Humble Oil & Refining Co., Gulf Production Co., Amerada Petroleum Corporation, Tidal Oil Co., Atlantic Oil & Production Co., Barnsdall Oil Co., Sun Oil Co., Shell Petroleum Corporation, Lone Star Gas Co., Stanolind Oil & Gas Co., Stanolind-Prairie Oil Co. and Delaware Peal Oil Co.

sented to the effect that any method of evaluating ultimate recovery is essentially an estimate and that this "pressure drop method" should be as reliable as any other. The argument is further supported by the fact



field programme. However, the application of this method of estimating ultimate recovery from water-drive fields and especially one similar to East Texas, in which all gas is in solution in the reservoir, is unsound and without reason. It is impossible to predict the nature of pressure decline in such fields because at present no method is available for evaluating the pressure maintenance of a water drive on the differential pressure in the production wells. Further, there is no way in which to foretell the effect of gas energy on the reservoir pressure when such a pressure is reached that dissolved gas begins to come out of solution in the formation. Generally, common thought among engineers is that "Utopia" will be realized when such a time comes that water-drive fields are produced at such rate as to allow the water encroachment to keep pace with the withdrawal of extraction, thereby effecting and maintaining a constant reservoir pressure. If such thought is valid the estimated ultimate production under such conditions would be infinite, thus proving the failure of this method of estimating ultimate recovery from water-drive fields.

It is believed, however, entirely possible that sooner or later subsurface pressures will be used in estimating ultimate recovery from oil reservoirs. It should be possible, by correlating subsurface information to develop a method for analyzing and computing these data in such manner as to arrive at a reasonably close estimate of reserves. Like other methods, this of course would not be infallible. It should be particularly well adapted to natural flowing fields similar to East Texas in which the boundaries are defined early in the development. Further, it should be superior to other methods in that the subsurface pressure data would supply us for the first time with tangible information in which all the characteristics of reservoir characteristics would be reflected. The practical development and application of such a method should prove a valuable contribution to the study of reservoir capacities and ultimate production.

Reservoir Pressure Declines

A definite means for observing the nature and trend of reservoir pressure decline is rendered through the use of subsurface pressures. It has been previously brought out that no dependable relationship exists between reservoir pressure decline and the rate of extraction from a pool. Therefore, the only method for obtaining this information is through actual tests. If a sufficient number of tests are taken over a pool, pressure contour plats may be drawn.

Fig. 7 shows an assembly of several of these plats. If the area between corresponding contour lines on each of the plats is filled in with colors, each representing a different pressure area, it is possible to note at a glance the various changes taking place in the reservoir pressure. A

clear, detailed discussion of the use and interpretation of pressure contour maps has been given by H. D. Wilde, Jr.[1]

Bottom-hole Pressure Records vs Pressure

Much has been written during the past year or two on the use of bottom-hole pressures as a guide for equitably prorating [illegible]. Nothing can be added to the subject in this short space [illegible] supplement subject in hand. Suffice to say that the proposed [illegible] appear to have merit and the outcome of their practical [illegible] awaited with interest.

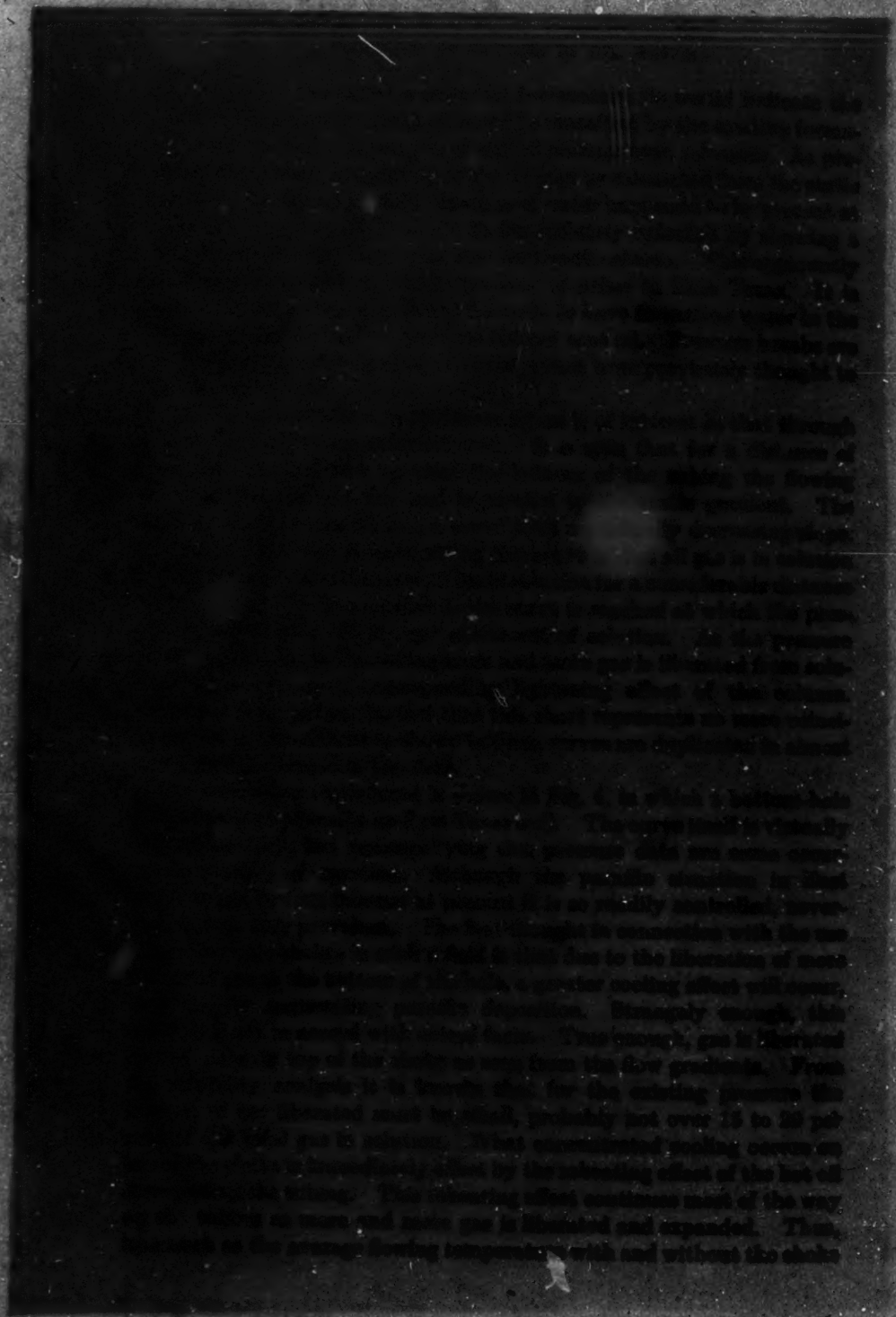
Application to Instrument Wells

Considerable comment has been published on the [illegible] various procedures to the study of oil reservoirs. As [illegible] said relative to their application in studying the [illegible] dynamics of oil and gas flow in oil layers. This [illegible] subject presents one of the most interesting possibilities [illegible] study and research in applying subsurface pressures [illegible] attention from this work is probably due in part to [illegible] and also to the immediate need for all possible information [illegible] relative to the problems of proration and unitization. [illegible] of application of subsurface pressure recorders [illegible] method for studying and comparing formations [illegible] oil wells and leases is identical with that for an [illegible] ever, the study of pressures in flow columns is [illegible] coming within itself a distinct part of the subject [illegible] new applications.

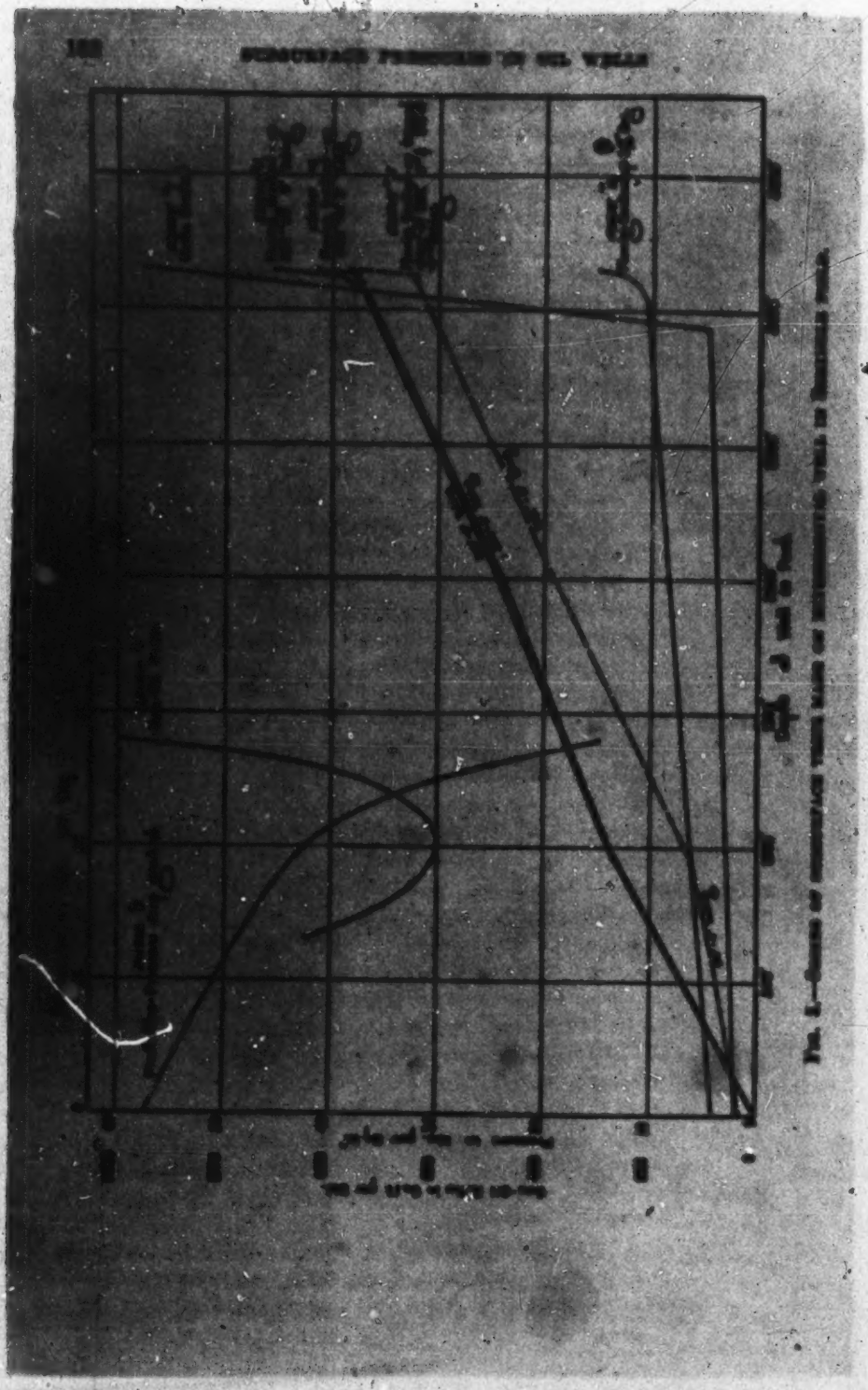
Undoubtedly, it has been noted that the pressure [illegible] reservoirs refer mostly to the bottom of the hole, [illegible] pressure, bottom-hole flowing pressure, differential [illegible] not the case for flow column studies since it is the [illegible] pressures from the top to the bottom of the hole and [illegible] of pressure gradient curves that provide the significant [illegible] followed an examination into this field of application by [illegible] through a study of graphic representations of actual [illegible] analysis of a few charts is made and the manner in which [illegible] portray certain definite conditions is noted. It is [illegible] how directly and with what degree of certainty conditions can be [illegible]

Fig. 1 illustrates an actual test performed on an East Texas well. [illegible] static gradient indicates the well to be of the [illegible] type, inasmuch as the pressure is sufficient to [illegible] the column of oil in the tubing to the [illegible]. By projecting the static oil column gradient [illegible]

[1] H. D. Wilde, Jr.: Why Measure Bottom Hole Pressure? A.P.I. Midcontinent Meeting, Tulsa, Okla., June 5, 1931.



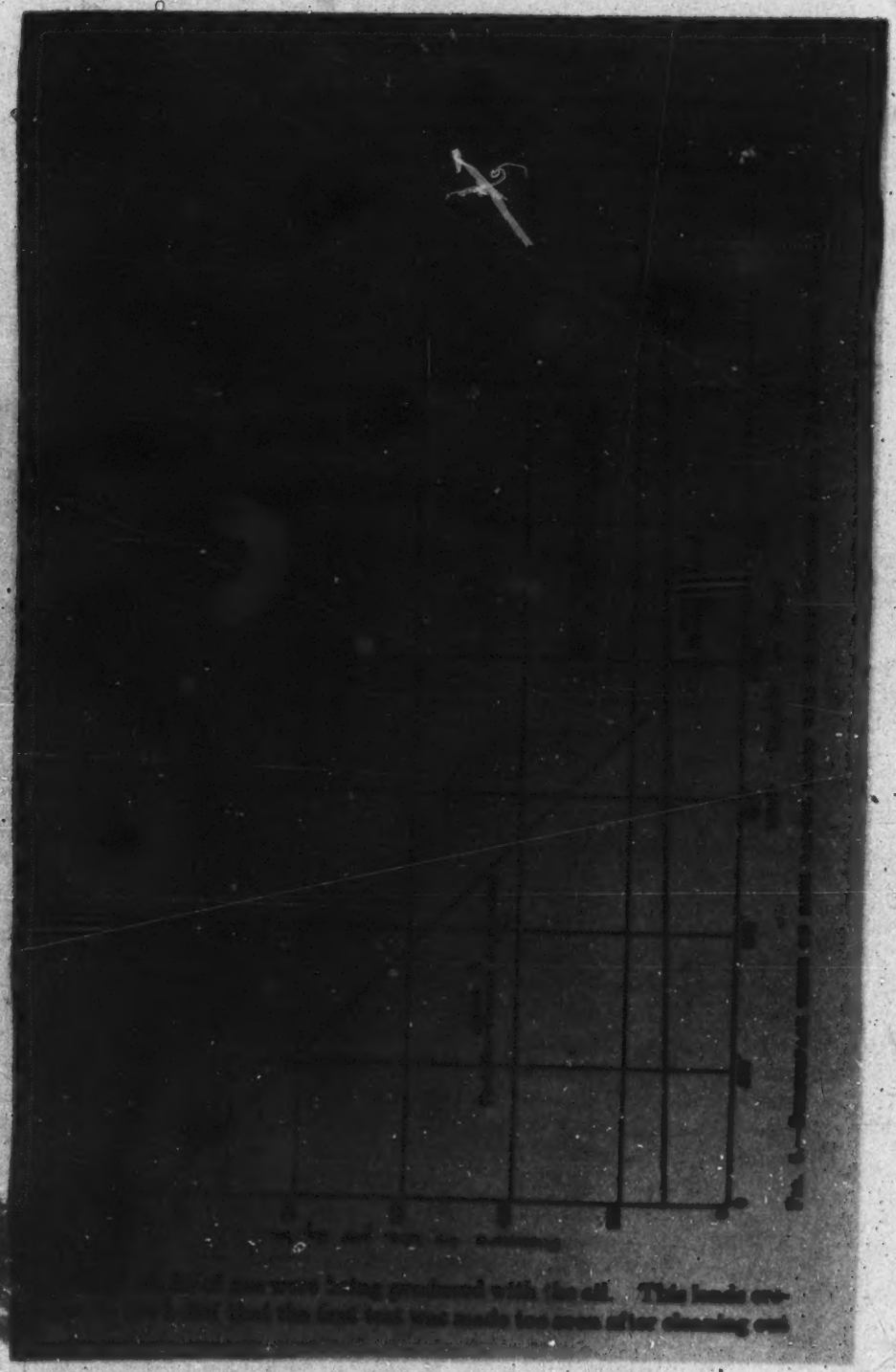




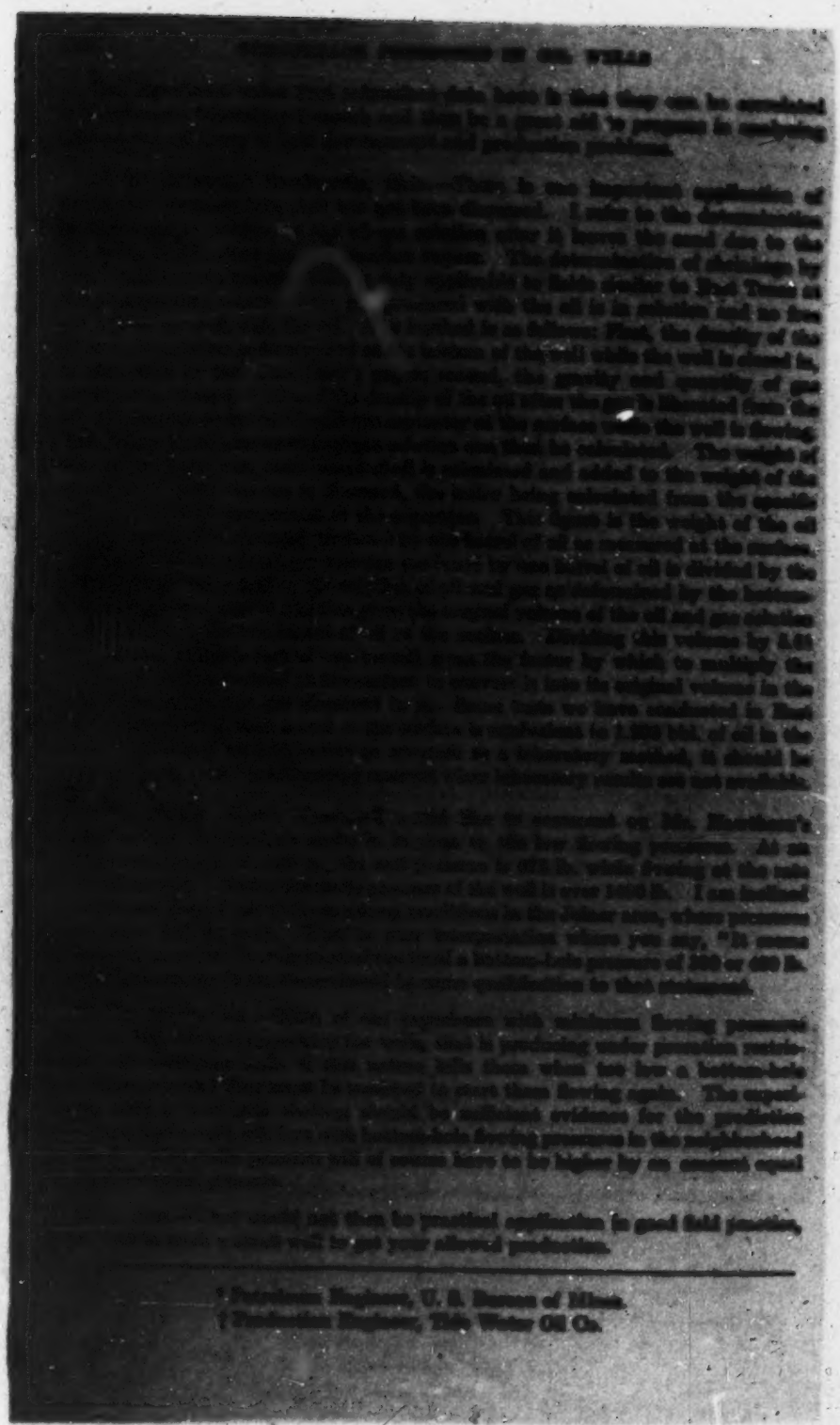
the final flowing pressure has been in the neighborhood of 700 to 800 lb. This figure appears rather high as from the above tests it would seem reasonable to expect flow to continue until the bottom-hole pressure has dropped to at least 500 to 600 lb. This should be of considerable interest to those companies operating in the field as it means an even greater flowing life than heretofore anticipated.

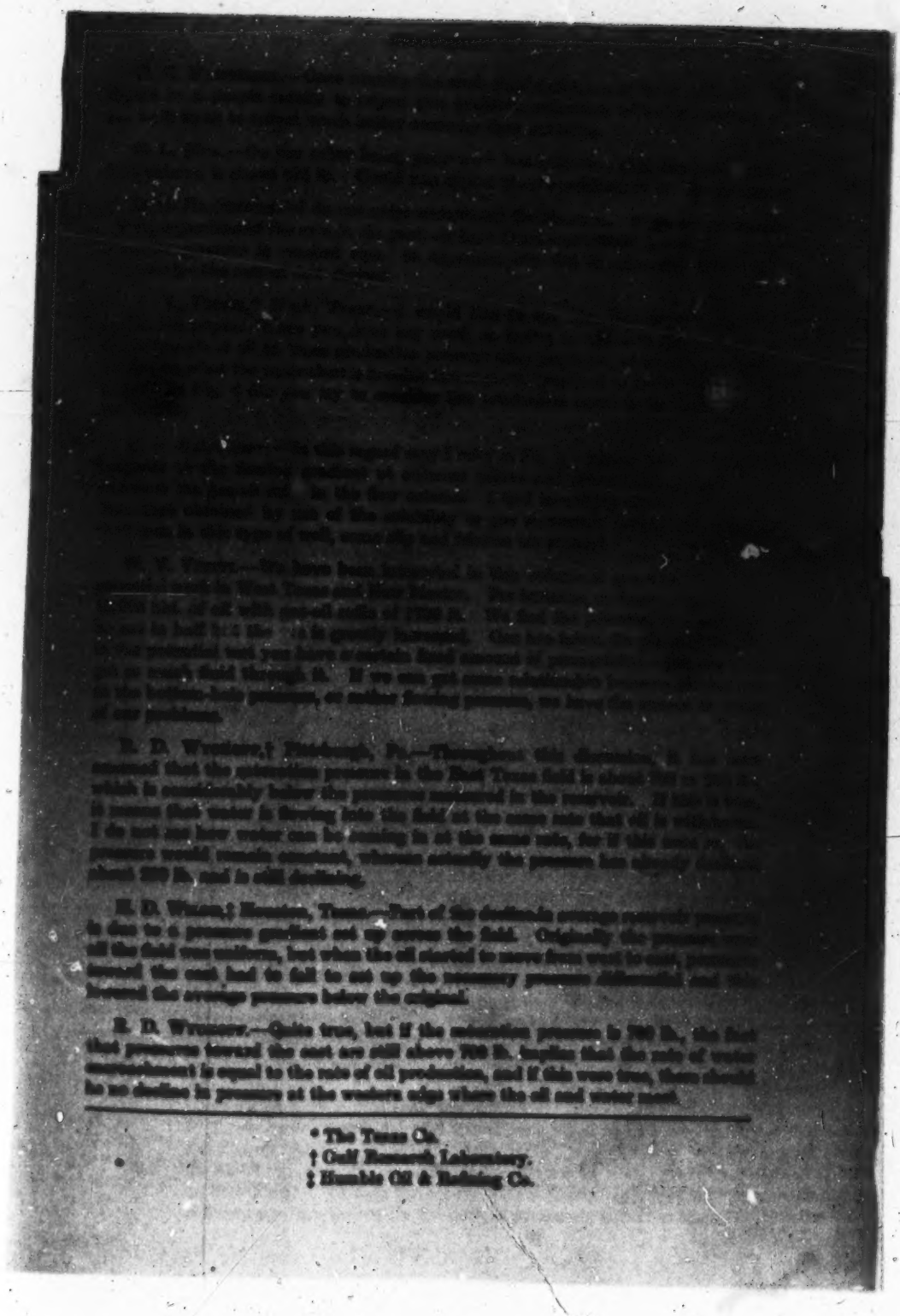
A series of experiments were conducted on a flowing well for the purpose of studying the nature of oil and gas flow in various types and sizes of columns. The results are shown graphically in Fig. 5. Attention is called to the extremely low bottom-hole pressure of 14.5 lb. while flowing through the 6⅝-in. casing. Curves 2 and 4 show the well flowing through 2-in. tubing set at different levels. The nature of the [illegible] the curves at the bottom of the tubing is significant. With the [illegible] 3110 ft., the gradient shows an oil-gas column coming up the [illegible] approaching the bottom of the tubing, while with the [illegible] 3126 ft., the break in the curve is sharp, thus indicating a [illegible] gas entering the tubing and lifts all of the top of a more or less [illegible] Curve 5 is a flow column gradient for a tentative setting of [illegible] as the replacement of 971 ft. of 2-in. tubing with 4-in., the [illegible] bottom of the tubing was decreased approximately 15 to 20 [illegible] The relationship between the production-pressure drop and [illegible] gas-oil ratio curve (Fig. 6) indicates the existence of a [illegible] apparently each points coincide closely at the same [illegible] of production. This should not be taken as conclusive as [illegible] to the nature and correlation of these curves are limited.

In Fig. 6 are shown the results of a recent [illegible] high-pressure, high gas-oil ratio well in the [illegible] County, Kansas. Inasmuch as no bottom-pressure [illegible] on the well only two points were available for drawing the [illegible] pressure drop curve. This curve is probably not a straight [illegible] likely takes a trend somewhat similar to that shown by curve 5. [illegible] peculiar condition is observed by noting the difference in [illegible] the static gradient and the flowing gradient. The static gradient [illegible] is to be steeper with a greater pressure drop in the column than [illegible] gradient. With the exception of this Kent Texas type well, it is [illegible] this condition will occur only in wells having high gas-oil ratios [illegible] reservoir pressures. The flowing gradient curve shows that while [illegible] producing at the rate of 12,000,000 cu. ft. of gas and 100 bbl. of [illegible] day, a pocket of fluid exists at the bottom of the hole. This [illegible] indicates the stratification of oil and gas in the formation. At a depth of 2327 ft. the well tested 4,000,000 cu. ft. of gas and no fluid. After deepening the well to a total depth of 2360 ft. and shooting it the production for 24 hours, it tested 12,000,000 cu. ft. of gas and 100 bbl. of fluid. It was at first thought that more gas as well as the fluid had been [illegible]









R. D. Wyckoff,† Pittsburgh, Pa.—Throughout this discussion, it has been assumed that the production pressure in the East Texas field is about 700 lb., which is considerably below the pressure maintained in the reservoir. It seems that water is flowing into the field at the same rate that oil is withdrawn. If the rate and later water can be passing in at the same rate, for if this were not true, pressure would naturally continue, whereas actually the pressure has already fallen about 200 lb. and is still declining.

R. D. Wyckoff, Houston, Texas.—Part of the decline in average pressure is due to a pressure gradient set up across the field. Originally the pressure in all the field was uniform, but when the oil started to move from west to east, pressure toward the east had to fall to set up the necessary pressure differential and thus lowered the average pressure below the original.

R. D. Wyckoff.—Quite true, but if the saturation pressure is 700 lb., the fact that pressures toward the east are still above 700 lb. implies that the rate of water encroachment is equal to the rate of oil production, and if this were true, there should be no decline in pressure at the western edge where the oil and water meet.

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* The Texas Co.
† Gulf Research Laboratory.
‡ Humble Oil & Refining Co.

E. D. WILLIS.—I disagree with this argument, for I believe the water can keep up with the oil as it is withdrawn and still be accompanied by a declining pressure at the water-oil boundary. There must be a pressure differential set up in the Woodbine sand lying west of the field to cause the water to flow into the field itself. If water were absolutely incompressible, the pressure at the boundary would fall almost immediately to the new low value and then remain constant. However, because water is compressible, the pressure is only falling gradually instead of immediately to the new value and hence the decline in pressure now being observed. The compressibility of the water is small, of course, but there are such tremendous quantities present in the Woodbine section to the west of the field that the effect on retarding the decline in pressure is very substantial. Computations of the rate at which the pressure at the water-oil contact should decline have been made and they agree reasonably well with the observed decline. This fact, together with the evidence as to the low saturation pressure, convinces me that the water encroachment is keeping pace with the oil removal.

MISSNER.—All of my work along this line has been in East Texas. What I say is particularly the case there and possibly true in other fields. It is very possible that differences in flowing permeability factors of different producing sand beds may be detected and determined by use of the bottom-hole bomb. When neighboring wells producing from the same formation, but with different degrees of penetration, have a different permeability factor per foot of penetration, it is apparent that the permeability of the section is not uniform. I have in mind one case where two offset wells were tested; one had a penetration of 20 ft. into the pay sand, the other 9 ft. The permeability factor per foot of penetration of the well with 20 ft. of sand was considerably higher than the one with only 9 ft. This indicates, I believe, that the lower sands are the more permeable, and the better producers of oil.

When considering the permeability factor of sand it is important that we consider the difference between per foot of formation, and per foot of actual sand penetration. Mr. Hawthorn shows in curve 3 a method of correlating the various sections of the field by a permeability factor. I also tried a similar method but used actual sand penetration instead of total formation penetration. The results obtained in this manner agree a little more closely than those where total penetration is used.

It is probable that the pressure at which gas starts coming out of solution is largely dependent upon the degree of agitation. We have conducted tests of a somewhat different nature than Mr. Hawthorn's but with a similar aim. In our test we obtained pressures at which the gas came out of and went back into solution. The values we obtained were slightly higher than Mr. Hawthorn's, but may be accounted for by greater agitation. I believe the time factor and rate of flow must be considered as well as the agitation.

Mr. Nye brought up the subject of whether or not wells will flow at the solution pressure. I think that the wells will flow at what is commonly considered the solution pressure (700 to 800 lb. gage). We must bear in mind the difference between flowing pressures and shut-in pressures. You cannot talk of flowing pressures in respect to shut-in pressures, but rather of flowing pressures at some definite rate of flow. It is possible that these wells can be flowed intermittently down to these low pressures without swabbing. I know of one well in an area where there is no free gas that has a flowing pressure of less than 600 pounds.

In the main, I consider Mr. Hawthorn's paper to be a very good presentation of the subject, but there is one point with which I cannot agree. He writes as if it were impossible to determine rates of pressure decline for wells or for a field in general, such as East Texas. To date there have been sufficient records of well pressures taken to determine rather accurately the rate of pressure decline for the field. This is espe-

cially so where a definite daily withdrawal is being taken from the field. At the present time it is generally considered that the pressure decline is close to one pound per million barrels of oil produced. This pressure decline should continue until the solution pressure of the gas is reached, or until the effect of the water drive is materially increased. This pressure decline rate must, of course, be determined experimentally from field observations.

The pressure bomb allows us to bring the laboratory to the well and thereby obtain far better results than would otherwise be possible. Whereas it was previously only possible to use the irregular and unreliable surface pressures, it is now possible by use of a bottom-hole bomb to obtain precision measurements.

D. G. HAWTHORN.—I see no reason because in the past the pressure has declined at the rate of one pound per million barrels of oil extracted, for expecting or predicting that this relationship will continue to hold true even though the rate of withdrawal is held constant. The time necessary to set up or establish a producing differential or gradient in the reservoir is a vital factor and must be considered.

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Journal of the Royal Society of Arts.

No. 3408. [illegible]

FRIDAY, JANUARY [illegible]

NOTICES.

RECEIVED 20 MAR 23

NEXT WEEK.

WEDNESDAY, JANUARY [illegible], at 4.30 p.m. (Short Juvenile Lecture.) "Science in Daily Life," by Professor H. E. Armstrong, F.R.S., F.I.C. The Secretary for Colonies, Lieut.-Colonel [illegible], M.P., will preside. (Lecture III.)

The lecture will be illustrated with experiments.

Further particulars of this lecture's meetings will be found at the end of this number.

SESSIONAL COVERS FOR PRESENTATION VOLUMES.

For the convenience of Fellows wishing to bind their present volumes of the Journal, cloth covers can be supplied, post free, for 2s. each, on application to the Secretary.

PROCEEDINGS OF THE SOCIETY.

FOURTH ORDINARY MEETING.

WEDNESDAY, NOVEMBER 29TH, 1922.

ADDRESS OF THE RIGHT HON. HENRY B. JACKSON, C.C.B., K.C.V.O., C.B., F.R.S., in the chair.

THE CHAIRMAN, in introducing the lecturer said he was the inventor of a very delicate electrical instrument which he had developed early in the war for the purpose of locating enemy gun positions. He would describe how, by careful research he had been able to apply the instrument to questions of practical purposes, making it a very accurate instrument for scientific acoustical measurements.

The paper was then read:

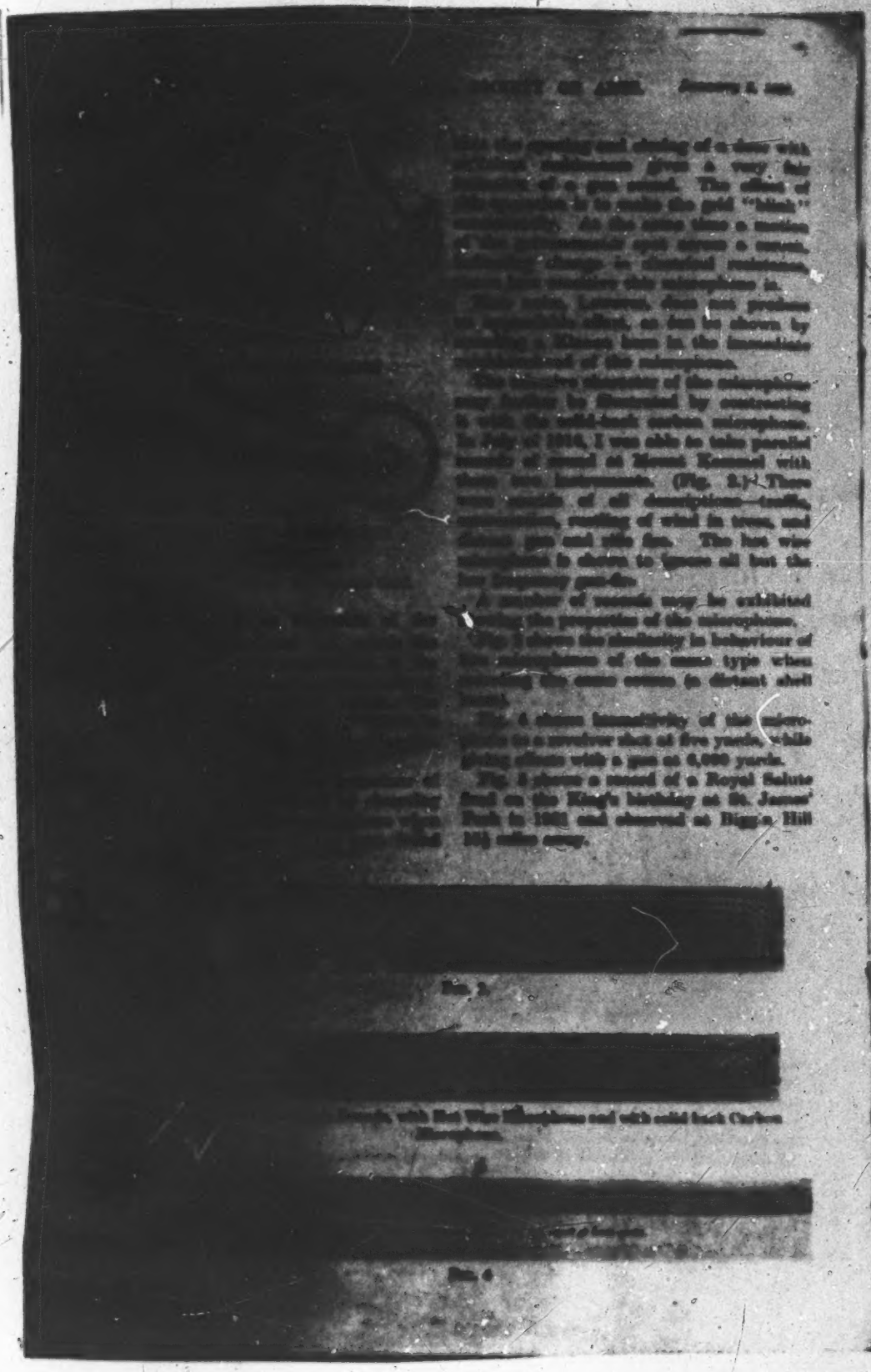
THE HOT WIRE MICROPHONE AND ITS APPLICATIONS TO PROBLEMS OF SOUND.

By [illegible] W. S. Tucker, B.E., D.Sc., A.M.I.E.E.

The subject of Acoustics or Sound has recently been brought into prominence by the application of the principles of wireless telegraphy to the location of a small enemy aeroplane, engaged in raiding London and the Department of Scientific and Industrial Research, and in the course of the work of this organization new lines and developments of general interest have been discovered. Some of these results have been described in this paper, and as they [illegible] the use of the Hot Wire Microphone, [illegible] has been made the basis of this paper.

[illegible] the first conception was suggested by Professor Wilson Hobbs, of Yale University, U.S.A., who showed that the microphone was not only the detection, but also the measurement of sound and vibratory motion.

In 1917 [illegible] designed to locate enemy guns and enabled accurately of a hostile gun or division. In one unit of which a small opening is made. When the explosive wave arrives at this opening [illegible] causing a small sound [illegible] that of air is projected into the [illegible]. In the path of this blast a very fine platinum wire grid is mounted, and by means of an electric current the grid is heated to [illegible] incandescence. (Fig. 1.) The effect of the blast is then to cool the wire, hence its electrical resistance and an effect [illegible] such as galvanometer of suitable type that a clear indication of the blast is demonstrated. The blast produced [illegible] [illegible] the current variations, and these again are dependent on the nature of the source of the disturbance. Hence the



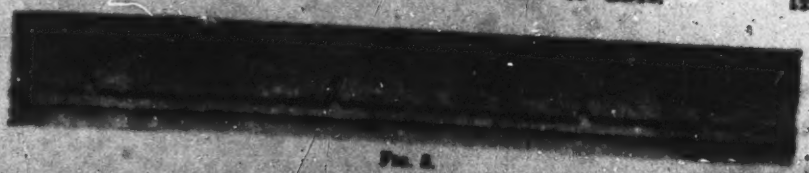


FIG. 6.

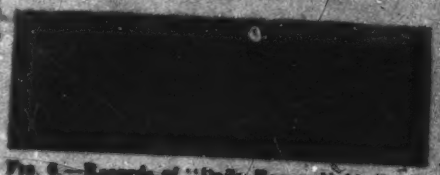


FIG. 6.—Records of "Daily Express" Air Bombs exploded over Hampstead Heath, as heard at Biggin Hill, July 14th, 1921.

Fig. 6 shows a record of nine bombs exploded on Hampstead Heath and observed at the same place, giving a range of 20 miles.

Distinctive records can be obtained from distant claps of thunder, and by means of three microphones sufficiently far apart it is easy to locate the origin of the lightning flash.

All these records have special characteristics by means of which either can be identified. It must be pointed out, however, that the sensitivity of the microphone depends, not only on the initial temperature and the dimensions of the hot wire, but also on the size of the microphone chamber. For the best reproduction of impulsive sounds, it is of advantage to use a chamber of about a cubic foot capacity and to make small holes or cracks in its walls to eliminate internal resonance.

From the above records it is seen that the microphone has an obvious application to such experiments as that recently conducted in Holland. The Meteorological Department of the Air Ministry asked me to try to obtain records of the great explosion of October 28th, and special arrangements were made for this purpose. Attempts were made to record the effect at Woolwich and Biggin Hill. The results of the observation at Woolwich are shown in Fig. 7, in which three well-marked effects are indicated. The times of arrival of the sound were respectively 19 mins. 39 secs., 19 mins. 45.5 secs., and 22 mins. 42 secs.

The records show, as would be expected, that the sound can arrive by a number of routes so far separated as to give separate impressions. The last effect which is the most prominent was very much delayed, and apparently consists of a higher pitched sound. The results obtained require careful study in conjunction with the known meteorological conditions, but the detail of this work cannot, of course, be described here. It is sufficient to say that from the known values of upper wind, the calculated

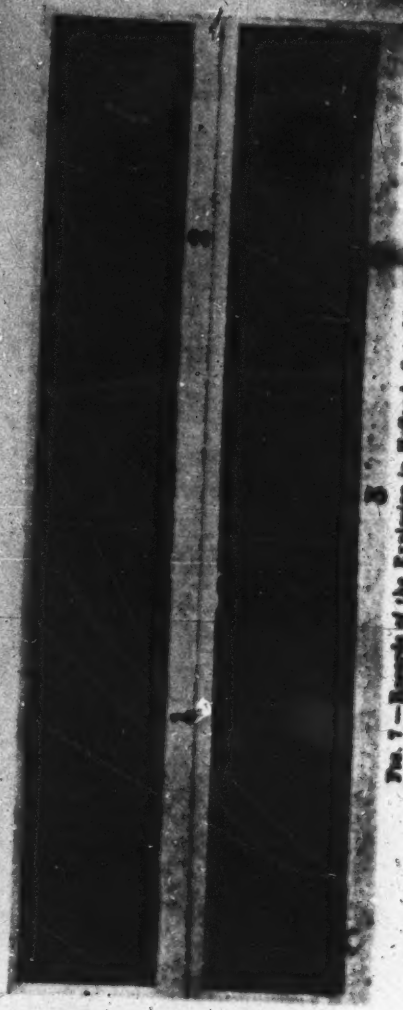


FIG. 7.—Records of the Explosion in Holland, Oct. 28, 1921.

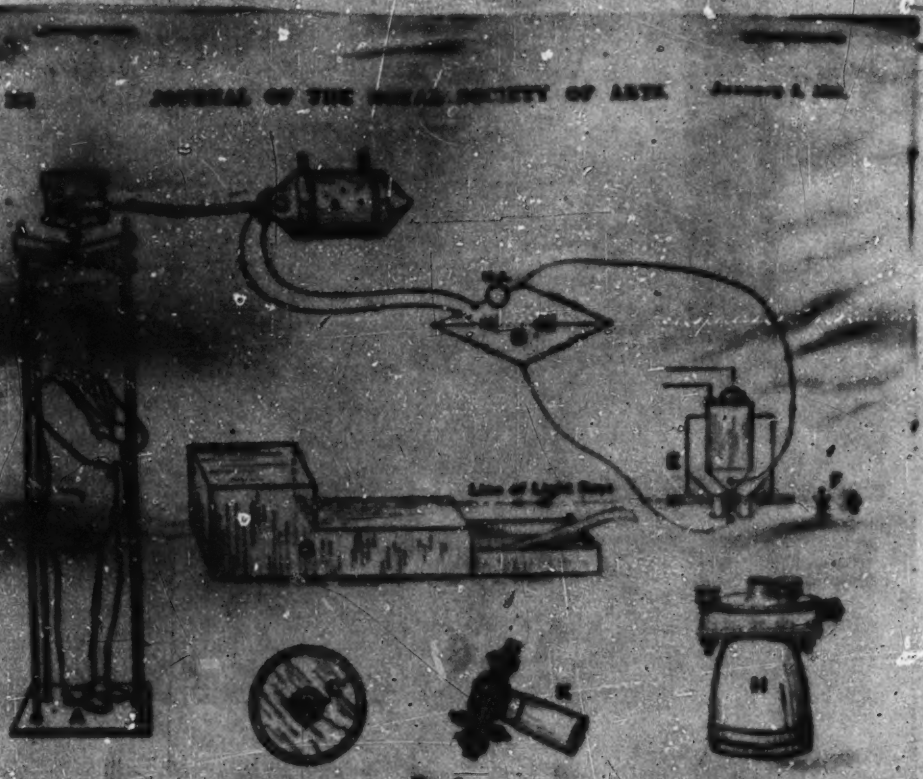


FIG. 8.

time to travel over the range (201.6 miles) is approximately that of the first valve spoiled.

The records of Hugh Hill are very interesting and appear to give strong evidence of transmission through the ground. It is the only one to report finally on our experiments.

Probably the one thing that impresses one most in the above instrument is its surprising sensitivity to low frequency disturbances—disturbances which produce no effect on the human ear, since they are below our range of audition. It is immediately obvious that such an instrument might be harnessed to apparatus for the measurement of vibrations in structures. One such device has been described by Colonel Haskell and myself[2] in a recent paper on "Recoil Curves as shown by the Hot Wire Microphone." Vibrations, some vigorous, some imperceptible, are communicated to the human body as the result of the forcible projection of the blood through the arteries due to the pumping action of the heart. Here the shakings of the body are transmitted to a diaphragm whose resultant motion pumps the air from a closed vessel to a microphone by a piece of rubber tubing, and the vibrating air sends the grid in such a manner as to indicate the nature of the body movements (Fig. 8). Associated with the pulse of the recoil records so obtained, we are able (i.) to identify certain movements in the blood, (ii.) to note how these vary with individuals in an apparently healthy state (Fig. 9), (iii.) to show that the peaks are higher during inspiration than expiration, thus indicating a breathing cycle, (iv.) to indicate how they vary when the body is treated with certain drugs, (v.) to observe how they change after exercise (Fig. 10) and (vi.) to show how they may suggest conditions of distress or of mental agitation (Fig. 11). In most recent apparatus the subject, whose recoil is being tested, is placed on a couch, so that he is in a more favourable condition for giving records free from those of the involuntary movements of the body.

This discovery opens up a field of research purely medical or pathological, and is quite certain of a proper elucidation of physiological and physical processes, it is necessary to understand thoroughly the meaning of the physical changes in the hot wire when subject to blasts of air, whether continuous, impulsive or alternating in character. One effect, however, must

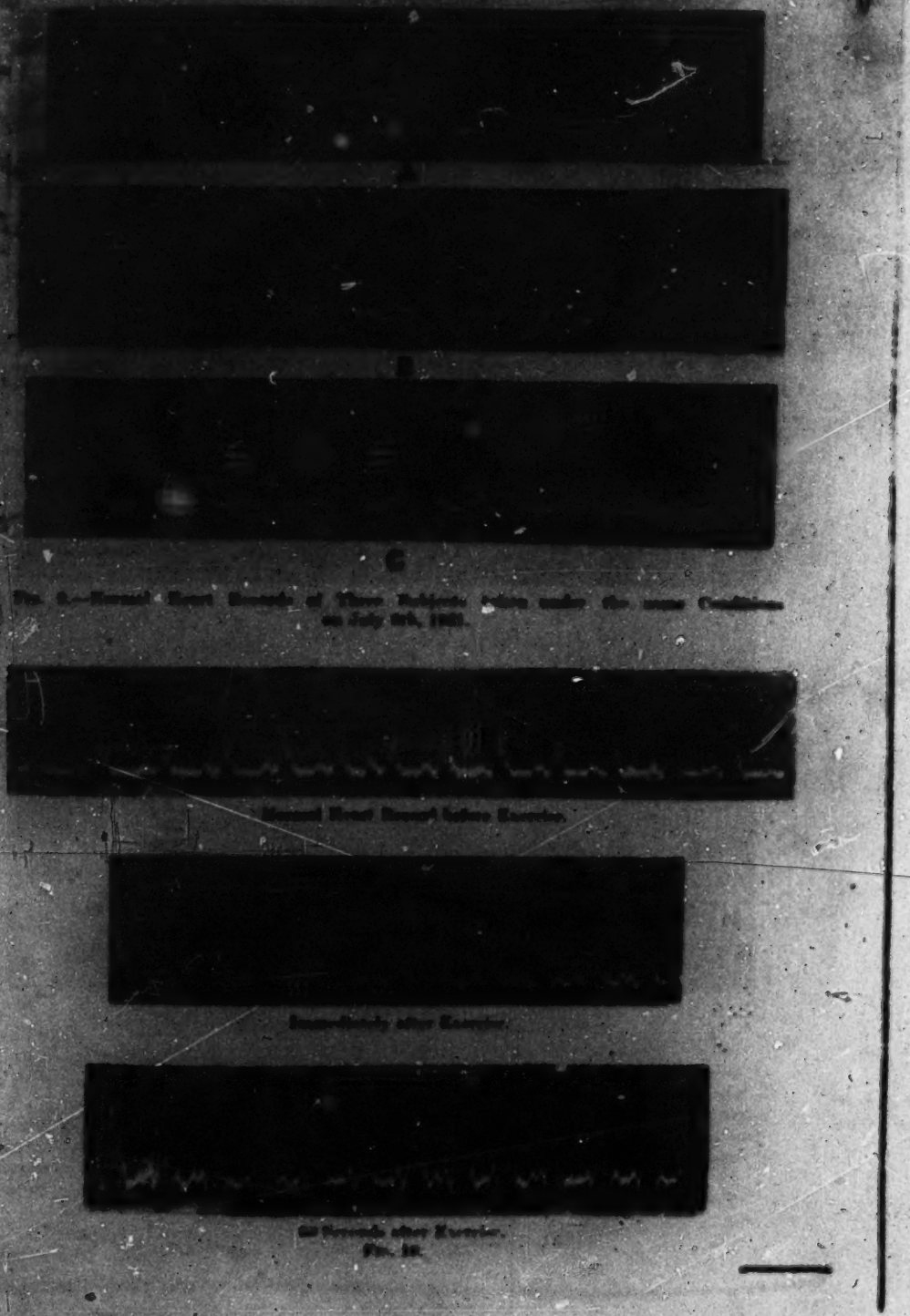




FIG. 11.—Showing Aortic Regurgitation.

be particularly referred to, viz., that the microphone wire is indifferent to the direction of the disturbing blast, since in both cases the wire is cooled, the resistance is diminished, and the record shows a succession of peaks entirely on one side of the zero line.

This statement must, however, be qualified by defining the position of the microphone grid. If the grid is vertical so that the hot convection currents from the wire are perpendicular to the motion of the particles of the vibrating air, the resistance change has twice the periodicity of these vibrations; but if the grid is horizontal, the resistance change tends to be in tune with them (Fig. 12).



(a) Grid Vertical.



(b) Grid Horizontal.

FIG. 12.—Microphone Records of Air moving in S.E.E.

The microphone as a measurer of impulses, is more difficult to explain than when used for the measurement of continuous sound. It was at first thought that the hot wire microphone could not be used for this purpose, but the remarkable magnifying power produced by resonance exhibited by Helmholtz, and its theory has received a complete treatment by the late Lord Rayleigh.[1] From known dimensions of the resonator, its magnifying power can be calculated, and it can be shown that

[1] Rayleigh's Theory of Sound. Vol. 2. Chap. XVI.

us to get sufficient disturbance with sounds of one predominating frequency to affect the hot wire.

In the above statement it was shown that for accurate recording, resonance should be discouraged in the containing vessel by perforating its walls. If, however, these walls were left intact, it was found that the vessel with its microphone orifice had a very definite note of its own to which it would respond with great vigour. Excited by the sound of the same musical pitch, the resonator, as we may now call it, produces intense vibrations in the neighbourhood of the hot wire thus cooling it, and moreover, cooling it periodically. This resonator is no new discovery. It was

resonance in a given case is confined to a very short range of frequencies, comprising about six per cent. of the mean frequency, so that it is only capable of responding to a range of about one musical tone.

The overtones to which it can respond are of high pitch, and are relatively feeble, this making it the most selective type of resonator known.

An approximate treatment of the theory of the instrument is given in a recent paper before the Royal Society,[1] in which the

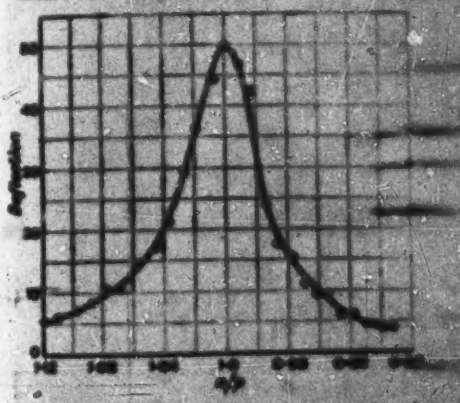


FIG. 13.

resonance curve of Fig. 13 is given. This has been obtained by subjecting the resonator to the sound of a siren whose pitch is gradually raised, and measuring the effect produced. This calibration of the instrument can also be demonstrated by a simple experiment.

It has already been stated that the resistance of the hot wire is not only diminished by the vibrations in the neighbourhood of the microphone, but this resistance is also subject to variations of a periodic character. If the variations of electric current resulting from such periodic changes be magnified by the valve amplifier, the resulting current is sufficiently large to affect a telephone. If, then, we have by the side in the neighbourhood of the microphone the response to a given note is maximal audible, and by means of a loud speaking telephone can be demonstrated to a large audience.

The microphone may be tuned by altering the volume of the resonator or by altering the dimensions of its neck—that is, larger volumes or a longer neck would be employed for a lower pitch. In general, alterations of volume is the most satisfactory way of tuning. For the sake of illustration, a microphone tuned to 512 vibrations per second, has one quarter the volume of one tuned to 256 vibrations per second, if all the rest are equal.

One of the advantages of this type of microphone is its insensitivity to other disturbing noises, as can be shown by substituting a galvanometer for the telephone, so that the response of the microphone is shown visually. Here the magnified alternating current is first made unidirectional by means of a crystal rectifier. A Klaxon horn and other disturbances were produced in turn, but the slightest kick on the appropriate note is easily detected.

Even keeping the microphone continuously in operation does not appreciably affect the speed clock makes. A very useful application of the instrument is for timing, and this is easily done by coupling it with observing the effect on a suitable galvanometer. For this purpose also, the hot wire microphone can be placed inside a room, and was shown by the galvanometer deflection the variation of intensity of sound at different points in the room.

Even in this form, the microphone has not shown its sensitiveness limit. It can be demonstrated that if the microphone be mounted with its axis perpendicular to the wall of a cabinet box, whose side consists of a sliding door, a small hollow sphere is obtained if the door be opened to a certain degree. The box itself becomes a resonator, and when used with the microphone enables the combination to be readily tuned to a sound of the correct pitch.

This phenomenon of double resonance, in which the sound waves come through the slits between the two boxes but in unison with the sound outside, should be of service in many scientific researches. The combination outside and can, but even moderately quiet and give a wide choice range of tuning, while at the same time giving high magnification.

A resonator of this type is shown in Fig. 14, and the hot wire is produced by a coil of nickel wire that was connected across the usual amplifier and detector. Fig. 15 is the side resonator, in the usual manner

[1] Rayleigh and Sutherland, Proc. Roy. Soc., A, vol. 98, p. 265.

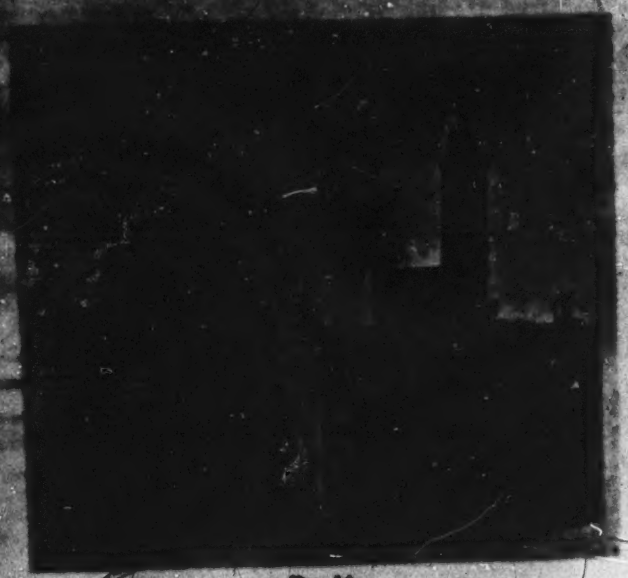


FIG. 14.

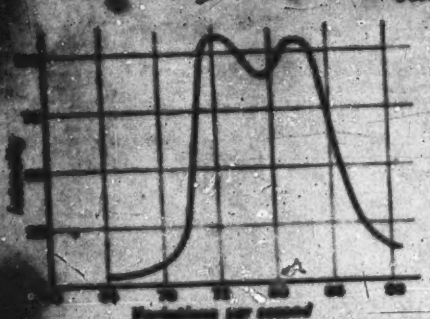


FIG. 15.

distance of sounds we have been able to produce and especially pick up inaudible sounds within the range. Its high selectivity also enables it to hear in the midst of disturbing sounds.

The greatest trouble that all microphones experience is disturbance due to wind. The hot wire microphone is specially susceptible, and much attention has been given to the solution of this difficulty. We are, however, greatly indebted to Mr. H. S. Player for the discovery of a very efficient wind screening device. This consists of the ordinary "loofah," the effect of whose fibrous structure is to break up any wind impulses without obstructing the passage of air or of sound. The microphone of Fig. 14 is protected with such a loofah screen which is here shown detached from the box front.

We may now turn to some investigations in which the microphone has been satisfactorily applied. Its consistency of behaviour enables it to be employed for the accurate comparison of sounds of the same quality, for it has been shown in the paper last referred to, that the ohmic change produced in the hot wire of the microphone is a direct measure of the intensity of the sound.

If the sounds to be compared are relatively feeble, a well tuned microphone would be employed, but if the sound is very intense, as in the neighbourhood of the Trinity House sirens, a microphone whose note is well below that of the siren is adopted. Thus, two fog horns were compared on the Channel Islands with a microphone of pitch 80 vibrations per second, that of the horns being 180 vibrations per second in each case.

If we use a source of sound of a given pitch, we can find out

(1) How the transmission of such sound is affected by weather conditions.

(2) How the sound is distributed in certain enclosures, such as rooms of different sizes and shapes, and how that sound is modified by opening windows or doors or distribution of the audience, or the furniture in a room.

(3) How the sound is modified, magnified or distributed by the intervention in its path of trumpets, reflectors or obstacles.

Dealing with the first class of experiment, on distant shots of considerable importance in navigation. The study of submarine echoes was developed at one station at Kingsgate, near the North Foreland, and the [illegible] Light Vessel for working [illegible] were followed on the map (Fig. 16).

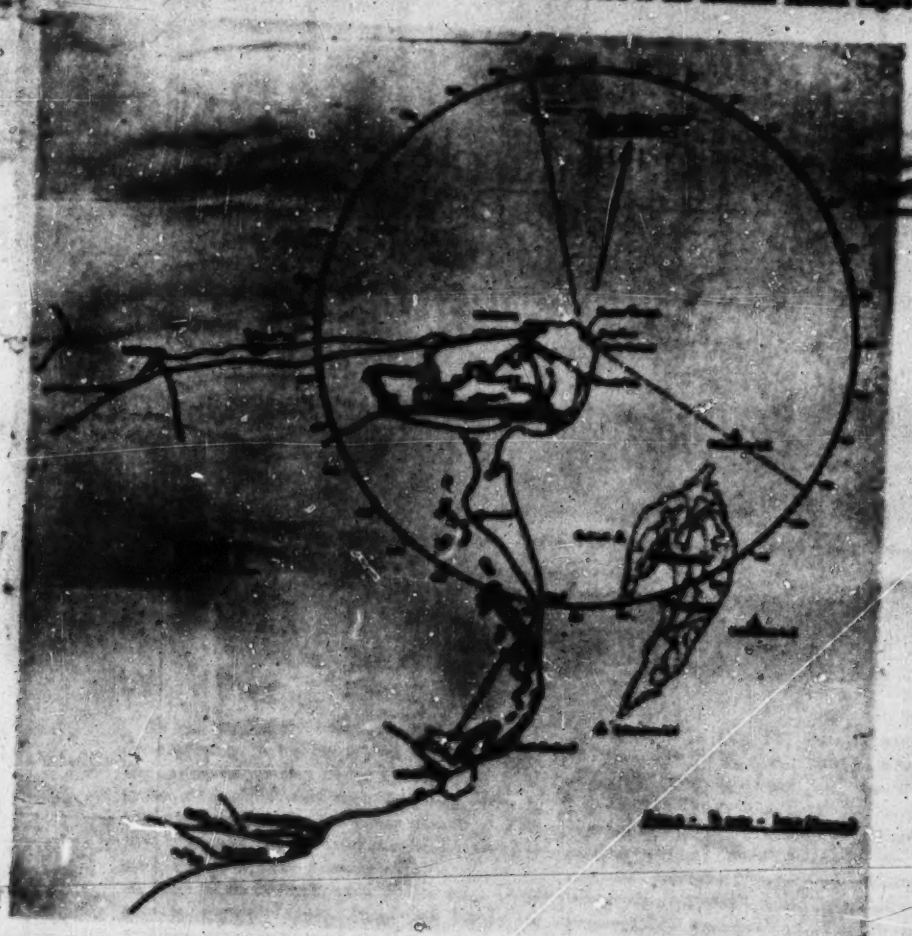


Fig. 16.

Fig. 17 shows how remarkably the intensity of the received sound varies on a typical English summer day when the sky may be clear or flecked with white cumulus cloud. The heights of successive pendo-responses to sounds emitted at minute intervals by the North Goodwin Light Vessel Siren on board at Kingsgate seven miles away. The instrumental effects were checked by eye, but it was only by the instruments that such large variations could be appreciated.

Fig. 18 shows a record of the North Light Vessel (three blasts of the [illegible] pitch) at a range of nine miles and [illegible] shows a record of the Kentish Knock Light

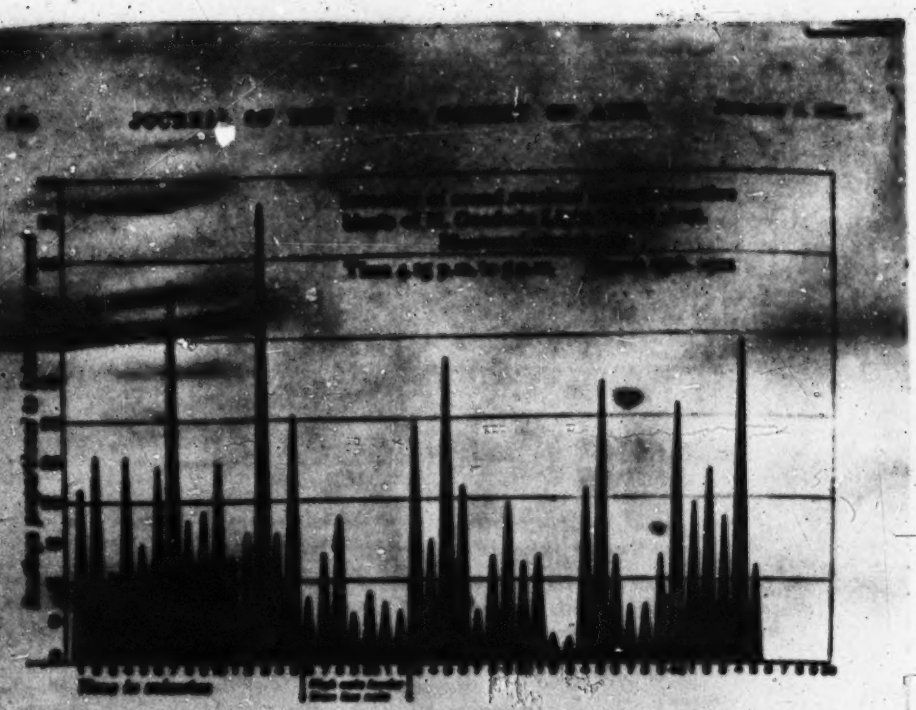


FIG. 17.

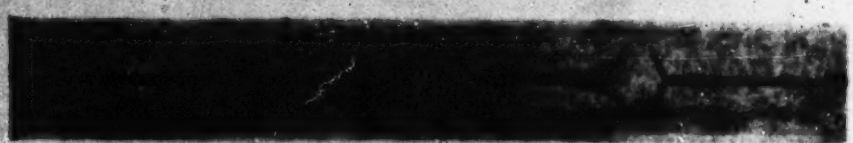


FIG. 18.—Record of the Tongue "Light Vessel Siren," 2 Blasts, Range 9 miles.



FIG. 19.

In all the above cases, doubly resonated microphones were employed, and through the courtesy of the Elder Brethren, a long series of observations were obtained, extending over a period of several months. For this work the North Goodwin Siren provided special blasts for periods of 15 minutes on four days in each week. We were thus able to record sound under all kinds of weather conditions and to obtain from the data thus supplied certain laws governing the conditions of audibility as affected by weather.

Toward the end of May of the present year the Elder Brethren afforded me the opportunity of working with the sirens on the Channel Islands, and I was able to take records on the Trinity yacht "Patricia," while cruising in the neighbourhood of the Casquet Rocks. With the microphone of Fig. 14, records were taken of the new Diaphone Horn which has recently been installed on the Casquets to replace the standard pattern siren. During the test, the effects of different conditions aboard were observed by taking records between the siren blasts. The vibration and ship's noises generally did not produce any serious effect. Fig. 20 shows the blast records as observed at a range of two miles. The abruptness of the increasing sound a valuable property of the diaphone is clearly demonstrated, and contrasted with the siren. No attempt was made to reduce the sensitivity of the microphone. At a distance of 4½ miles the sound was still too intense to obtain the whole of the record on the sensitised paper strip using full sensitivity. The time at our disposal prevented our working on



FIG. 20.—C. Diaphone and Siren Records Compared. Range 2 miles.

extreme ranges, but it is believed that a range of at least 20 miles could have been recorded by the microphone. The superiority

bearings gave no such indication, and the North Goodwin siren—slightly to the south—gave a sound perfectly free from echo.

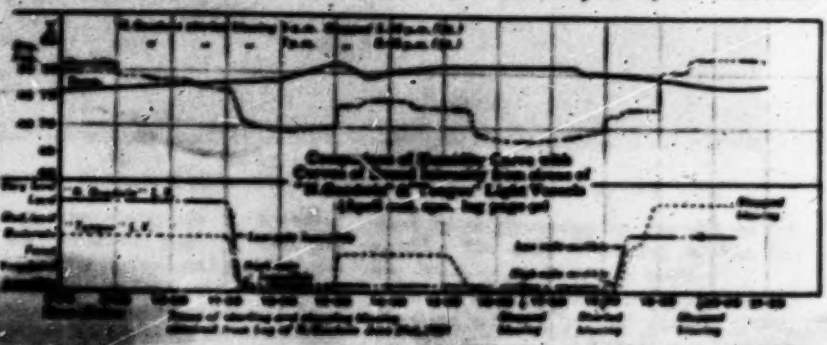
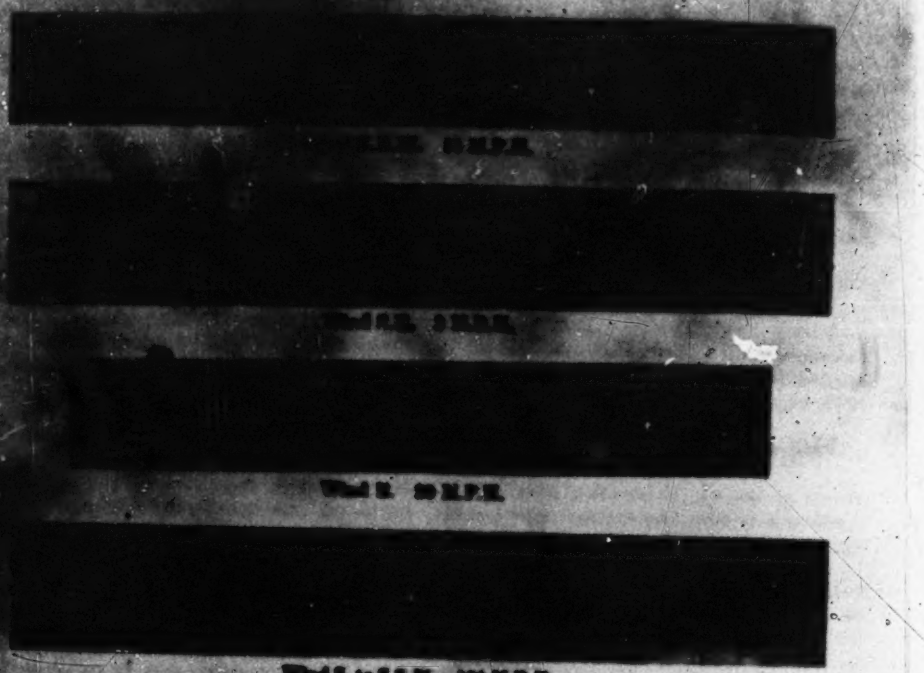


FIG. 21.

Fig. 21 shows the effect of a shifting fog on the audibility of the North Goodwin siren, and its intimate relation to changes of humidity. It is seen here that at points where the humidity undergoes sudden diminution there is corresponding diminution in the sound of the North Goodwin siren. Variation in humidity means variation in fog-density and during the interval of silence, shown in the diagram, there was a fog bank lying between the source and the ear, but never completely enveloping both. A uniform fog is even more satisfactory for sound transmission than average clear weather. It is the variation in fog density which is so fatal to good listening. This evidence is in keeping with the late Professor Tyndall's observations at the South Foreland.[4]

It is generally accepted that sound is

4. Tyndall's Sound. Lecture VII.



Wind E. 20 M.P.H.

Wind E. to S.S.W. 12½ M.P.H.

FIG. 21.—Variation of received Sound with Wind (Sound approaching from S.E.).

Sound travels favourably in a following wind. Fig. 21 shows, however, that this rule is frequently broken, and has directed our attention to a fuller study of upper wind and temperature conditions. If a following wind has a velocity which increases as we ascend it is favourable for sound. The same conditions obtains with an adverse wind which diminishes in strength as we ascend. The cases illustrated in Fig. 22 are examples of these two cases.

Fig. 22 is of interest as it shows a record of sound arriving by two distinct paths. The day was clear and there was a strong following wind, whose velocity alternately increased and decreased as the height we-

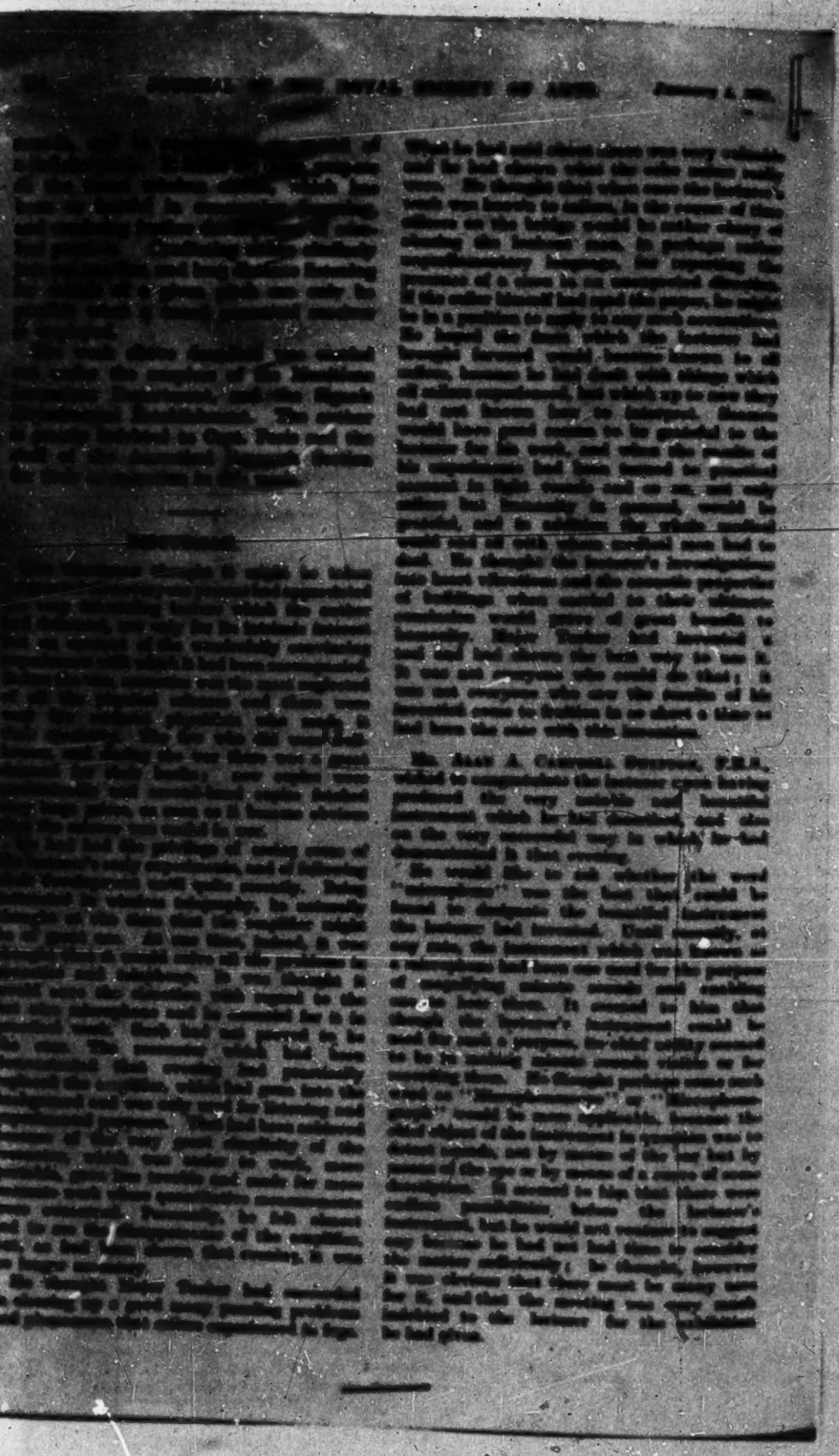


Wind E. 20 M.P.H.



FIG. 22.

[illegible] the object is the source of [illegible] [illegible] [illegible]



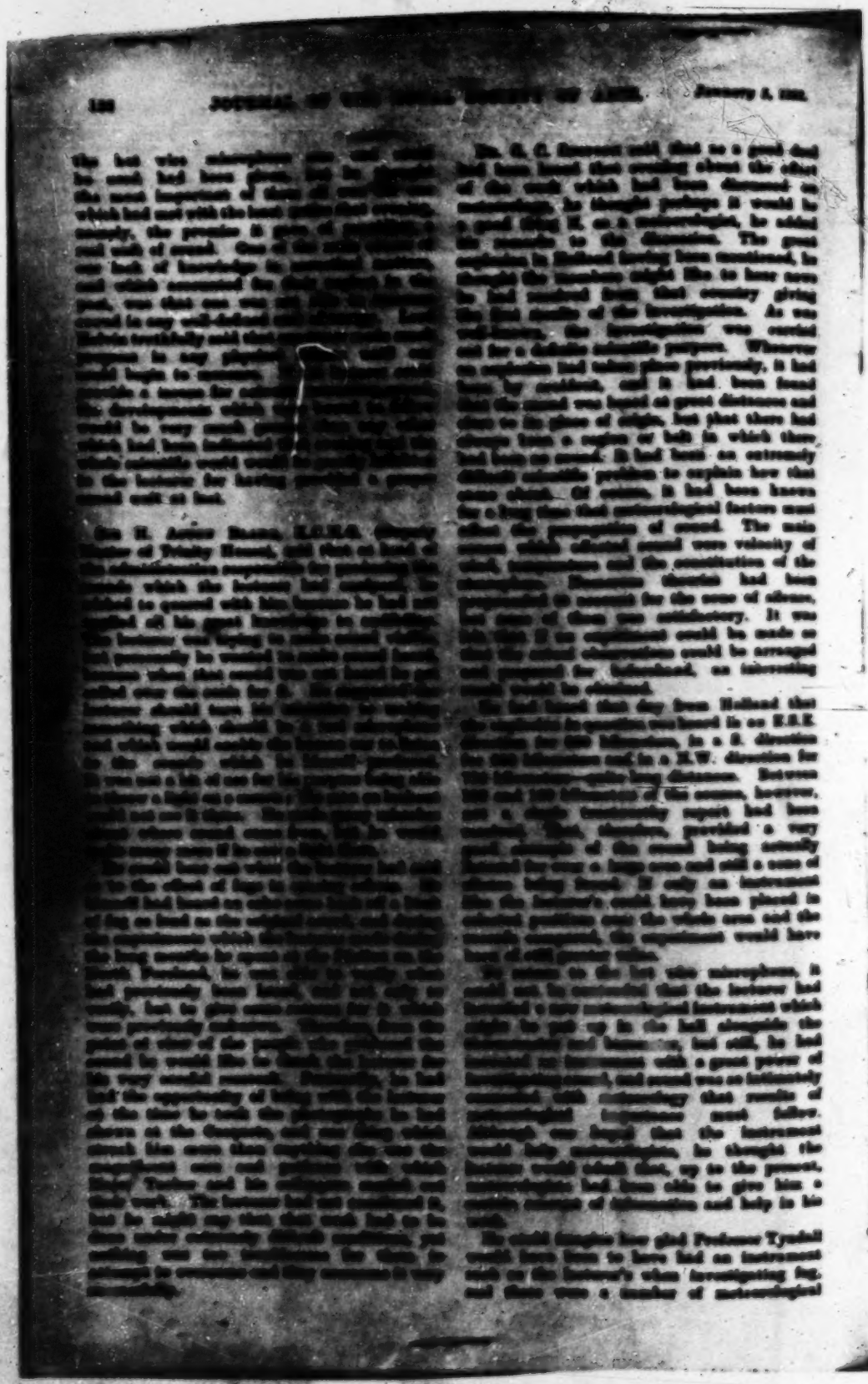
Lieut.-Col. A. Cowan said that for the past three years he had been chiefly responsible for the Lectures, but he had not been responsible for the work. He thought everything apart that the Society's Secretaries had done remarkable one, and included in it everything the saying with regard to "heating events the phenomenon." There was one point in the paper on which he would like to enlarge. He thought the appointment of the Society's Lecturers to mechanical research would be of just the highest, as all events one of the most important of the developments. The examination of electric vibrations or variations in temperature and electrical apparatus would be found, he thought, of the greatest value and importance.

Colonel C. E. Heath, C.B.E., R.E., wished to associate himself with other speakers in thanking the Lecturer, with whom he had been in official relations on such during the past three years. It might be of interest to the Meeting to know the origin of the Lecture with which Major Tucker had started. In 1901, he was desirous to conduct the medical examinations of boys, and it was decided to weigh them accurately. When weighing them on a weighing machine, the only one obtainable at that time, it was noticed that the head moved. He had noticed that previously, but had simply noted. A year passed by and then a Committee, Colonel Heath being chairman, met to discuss the matter, and he found that in the year 1901, and probably the years then, Major Tucker, with Lieutenant Hall, had been carrying out experiments of the head with a few comparatively simple instruments, and with other instruments of the head part of scientific work of the kind in connection with recruiting, produced the results which had been described in the first portion of the paper, and all the physical part, which was of the greatest value to the Lecturer.

They usually began with what was the use of making head records of the kind in question, when one could learn to know with a glance. The answer was that by recording a person's head they knew exactly what it was. One person of the body, but in the head, and by recording head form it, as explained by the Lecturer, they were taking photographs of the head and keeping them for reference. Many cases had been recorded where men had been wounded in the head, and by recording the head form it was possible to identify the man. In connection with the Lecture, the Lecturer had also referred to the question of the identification of individuals. It should be possible by their records to get such data if the records were made carefully, and those records should be preserved the archives of this or any Society. Such records were extremely useful for many purposes, and he had received letters from many persons of the value of having an accurate record of the head. When the Medical Officers should not any other would be extremely overjoyed if they saw the records of any of the individuals shortly after they enlisted, or perhaps [illegible] with their being wounded, or [illegible] of wounding was at once apparent. Records of the could be determined. The Lecturer had also referred to the question of the [illegible] and the height of [illegible]. The work in that direction had not been neglected, but it was in the hands [illegible]

The eight measurements recorded which he had taken. He was asking for [illegible] to get a head record, and it occurred to him to say the proposed object of [illegible] should be the very thinking of the possibility of the [illegible] by the police. A man might be [illegible] possibly, with records taken by [illegible] recognised. Many cases of it [illegible] in this matter, the Chairman and the Secretary [illegible] they can help us [illegible] good. There was [illegible] to [illegible] the records of the [illegible] [illegible] have also the effect of a [illegible] which [illegible] easily [illegible] and [illegible] as rapid, and the other [illegible] a [illegible] of a [illegible] who did not [illegible] a [illegible] [illegible] taking [illegible] [illegible]

[illegible] of [illegible] and [illegible] [illegible] [illegible]



problems the lecturer had not mentioned that evening in which it might be useful, such as finding out the velocity of the air in the upper atmosphere, which was of great importance for many meteorological problems, and also for the application of meteorology to such things as gunfire.

Before sitting down he would like to draw attention to an aspect of the work which, to him, was very striking, namely, that it had been done entirely by Government, at Government expense in a Government Institution. It was practically pure science, and it was, he thought, an interesting sign of the times that Government had worked and was working along these scientific lines. Before the war very little was known of the matter, but now our had the three great fighting forces, the Army, the Navy, and the Air Force, joining together and employing men like the lecturer to investigate scientific problems. What was still more striking was the fact that an investigation which had started with the idea of fixing the position of guns so that not only the guns, but the men working them might be wiped out, had been adapted to things which were of use to the people at large and for the investigation of medical problems and as a help to investigators. It showed that one could not touch any scientific problem even for assistance in war without getting some great advantages for peace.

Dr. L. Imanuel wished to add a few words to emphasise the importance of the lecturer's work from the point of view of the Merchant Service. Personally, he was an official of the Chamber of Shipping of the United Kingdom, and he could testify that it was of the very greatest interest to those connected with merchant shipping to know that the invention which had been described, and which was originally designed for war purposes, was now proving useful to the Institute of Marine Engineers who were using it in order to differentiate between one type of steam and another. The publication of the various log sheets which gave warning to seamen was a matter of the very greatest importance to ship-owners, but, while in that regard it touched shipowners directly, it also affected them in another way indirectly, in so far as the Meteorological Office, who kept them informed of everything that was happening between the sun and the horizon in the various portions of the globe, were assisted by it. In addition to the kind words which the Chairman, representing the Admiralty, had spoken, he thought it was not out of place to add something as a representative of merchant shipping.

Mason Turner, in reply, said that with regard to the gales raised by Mr. A. Shapland Swinton on to the lecture platform, the question of making the instrument had caused a great deal of handwriting and discussion, and the word "atmometer" resulted simply from a difference of opinion among all the people concerned. It was really a measurer of blasts of air caused as a result of sound, but it was extremely difficult to think of a word which was sufficiently simple, without being pedantic, to describe how the instrument worked.

With regard to Sir Aston Blake's remarks, he would like to say that he and his colleagues had very much at heart the kind of work Sir Aston described—how to make sounds audible to the mariner, knowing that the ear was of more importance than any instrument which could be devised. The only way in which he could help in that matter, however, was by devoting his attention to the production of sources of sound, and he was glad to say that his researches had enabled him to follow out this line of work. The applications it had met in testing sounds were they had been produced; unfortunately, at the present time, sufficient progress had not been made to enable the atmosphere to be used with great effect, but that was a matter which was in the forefront of their programme and he hoped they would be able to supply the Elder Brethren with the information they required.

The Chairman said that a very interesting lecture had been followed by a very good discussion, which he hoped would be duly appreciated by those in authority. He asked the Meeting to accord a hearty vote of thanks to the lecturer for his interesting paper.

The vote of thanks was accorded unanimously and the meeting then terminated.

[redacted]

In the Journal of 1922 (Abstracts, page 97), is an article headed "Engineering Work Outside Industry."

This item was drawn to the attention of the Royal Society of Arts by H. G. Ramsay in 1921. Samples also of that item were submitted to the Key Industry Committee and to several persons, all of whom pronounced it equal to the best British line.

Mr. Brown, an Englishman, at the head of the Columbia Agricultural Department, had some pamphlets for the Columbia Government on this item, and promised it [illegible] of Fine Open.

The Islands have never properly developed it, and it is unlikely [illegible] under the names of Sensible Knitting, Sensible Jumper, Sensible Stockings and Fine Hose.

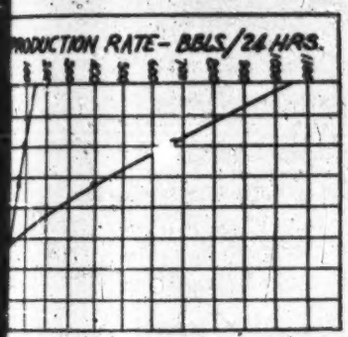
The name of Fine Columbia is [illegible] as it gives satisfaction in all of the Tropical and South American countries from the equator south to 35 degrees south of the equator. In other words one representative is in different [illegible] one representative is in different [illegible] in [illegible] the [illegible] of them; but by showing up the bale of the season, coming on right

ottom Hole Pressure Bomb Aids in Selection of Equipment for Wells

By HAROLD K. IHRIG

This article describes the use of recording type bottom hole pressure bombs in securing necessary information for selecting equipment in large pumping wells. The data gathered may also be plotted as curves and by the projection of these curves arrive at a close approximation of the total volume of fluid a well is capable of producing per day.

Considerable work has been done past several years on the use of bottom ressures as applied to flowing wells as a for equitably prorating restricted fields and ance in the selection of proper production and equipment. It is only recently, how- hat the use of bottom hole pressure bombs me into a very widespread use as a means rmining fluid level conditions and the vol- f fluid a pumping well is capable of pro-



—Representative test curves in which il rates of oil and water production are d against the respective bottom hole pressures

, and thereby furnishing a basis of great nce to engineers in making suitable selec- of producing equipment that will, as nearly ible, produce the well to capacity.

those pumping wells making large volumes er the operator is sometimes at a loss to ine what extent he is pumping the well and is naturally undecided as to what type ping equipment to use because of the large ditures entailed in making any major ge.

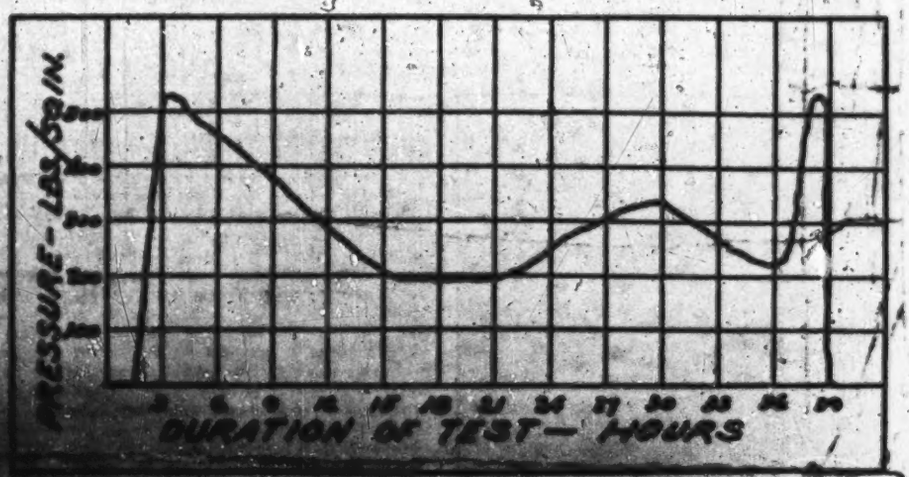
a means of arriving at a close approxima- of the capacity of a pumping well with a fluid level the recording type bottom hole e bomb has been of great help and is re- g an increasing amount of use. There are l types of these recording bottom hole bombs e market at the present time and while there wide difference in the working principle, bility, ruggedness and cost the results ob- are comparable and, in nearly all cases, le.

et a typical case in which the use of a h hole pressure bomb of the recording type d to be of great value to an operator who ronfronted with the problem presented by a pumping a large volume of water and a com- ly small volume of oil, due to the equip- with which the well was being produced. ution was to select other pumping equip- that would move a large volume of fluid thereby increase the oil recovery from the . The handicap of not knowing the approxi- total volume of fluid the well would pro- nor the probable volume of oil the well d produce, in case the well was pumped, made his selection of new equipment, other t might be, a bill of sale proposition. In e consideration of the use of a bottom hole pressure bomb in the use of a bottom hole pressure bomb ermine without question the total fluid ity of the well.

pressure element used in this type of bomb consists of a coiled tube, one end of which is closed and the other end connected to the inside of the bomb. A steel stylus is attached to the free end of this tube in such a manner that any variation in pressure will cause this stylus to move in a vertical plane. This steel stylus, to record the variations in pressure in the tube, moves over a card of highly sensitized paper which records the path made by the stylus. This card is of such size that it is formed into a cylinder within the bomb and is rotated by the small timing mechanism in the bomb. Each pressure tube must be calibrated against a deadweight tester to determine the length of travel made by the stylus per 100 pounds per square inch pressure. As the recording medium, or card, revolves once in 24 hours, and the timing mechanism usually runs for a period of from 36 to 42 hours the ultimate curve recorded is one in which the last 12 to 15 hours overlaps the part of the curve drawn in the first 12 or 15 hours of the test. Figure 1 is an approximate reproduction of a recorded test with the overlapping part of the curve transposed to form one continuous line.

The bomb was inserted in the gas anchor immediately below the pump being adequately cushioned by both steel springs and rubber to keep it as free from vibration as possible. The tubing was then run into the hole, the rods run and the well put to pumping. The well was pumped at maximum rate for approximately 21 hours then slowed down for a period of 9 hours when it was again run at the speed used at the start of the test. The curve drawn by the bomb, shown in Figure 1, will reveal the entire operation. The rapid rise of the curve is due to the increase in pressure created by the submergence of the bomb as it was lowered into the fluid, and reveals a bottom hole pressure of 825 pounds per square inch. The rapid drop in the bottom-hole pressure, caused by the pumping of the well, to a pressure of 190 pounds indicates that the equipment used to produce the well was operating at its maximum capacity and had lowered the fluid as far as it could. Production at this point was at the rate of 95 bbls. of oil per day and 670 bbls. of water per day. The operating equipment was then slowed down and the fluid level allowed to rise. With the well being pumped at about two-thirds the usual speed we find that the fluid came up the hole sufficiently high to create a pressure of 325 pounds per square inch on the bottom of the hole. Production at this point was at the rate of 53 bbls. of oil per day and 390 bbls. of water per day. By plotting the several pressures against their respective production rates we are able to arrive at two curves which when projected will give a close approximation of the true productivity of the well. Figure 2 shows these figures plotted and the curves extended. It will be noted that at 825 pounds bottom hole pressure the production rate is zero, at 190 pounds bottom hole pressure the rates of 95 bbls. of oil and 670 bbls. of water per day, and at 325 pounds bottom hole pressure the rates of 53 bbls. of oil and 390 bbls. of water per day. By extending a line from the zero production point through the two oil production rates and to the zero pressure line, and doing the same with the water production, we find that the well is capable of producing 145 bbls. of oil per day with 1,050 bbls. of water per day.

With the knowledge that the well in question is capable of producing 1,195 bbls. total fluid, the operator of the well has some definite information upon which to base his decision in the selection of new equipment to produce the well.



Graphical reproduction of bottom hole pressures in a pumping well. The cross section- ...ure was obtained on the card after it was taken from the well, and correlated with the time ...d test, and the corresponding pressures by use of the calibration curve for the bomb



DEFENDANT'S EXHIBIT K-8

BOTTOM-HOLE PRESSURES IN OIL WELLS*

By C. V. Millikan,† Tulsa, Okla. and Carroll V. Sidwell,‡ Seminole, Okla.

(Tulsa Meeting, October, 1930)

There is nothing more important in petroleum engineering than a definite knowledge of the pressure at the bottom of an oil well at any existing operating condition, and the relation of this pressure to the pressure within the producing formation. A knowledge of bottom-hole pressures is fundamental in determining the most efficient methods of recovery and the most efficient lifting procedure, yet there is less information about these pressures than about any other part of the general problem of producing oil.

Determination of Bottom-Hole Pressures

Bottom-hole pressure may be calculated or determined by several methods. On an inactive well it may be calculated from the fluid head or, if the well is shut in, by adding the casinghead pressure, the static head of the gas and the fluid head. In wells flowing naturally through tubing the pressure at the bottom of the tubing may be calculated by adding the pressure at the casinghead be-

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† Chief Production Engineer, Amerada Petroleum Corporation.

‡ Production Engineer, Amerada Petroleum Corporation.

tween the tubing and the casing and the pressure due to the weight of the column of gas, but there is always possibility of error caused by fluid being in the annular space above the bottom of the tubing. If a well with tubing is flowing through either the annular space or the tubing, sufficient gas may be injected through the static space to insure that it is free of fluid but not sufficient to establish an appreciable friction loss. The pressure at the bottom of the tubing can then be calculated by adding to the pressure at the tubing head the pressure due to the weight of the column of gas. This is probably the most accurate method of calculating bottom-hole pressures. In wells flowing by gas-lift, the pressure at the point the gas enters the flow may be calculated by a gas-flow formula. Several types of pressure bombs have been used to measure the pressure at the bottom of wells. One is a piece of steel tubing with a check valve in the bottom and a connection for a pressure gage at the top. It is lowered into the well to the point at which the pressure is

1665-PH

Density of Oil-gas Columns from Well Data

By William Vernon Vance,* Ware, Texas

(Texas Meeting, October, 1930)

Actual field data from several wells are used to illustrate the application of the method of determining the average density of the fluid column in a flowing oil well in the Yates field, Pecos County, Texas.

The depths of the wells in the Yates field vary from 900 to 1700 ft., depending on surface elevation and the location of the wells on structure. Production rates over 3000 bbl. per hour have been determined and many

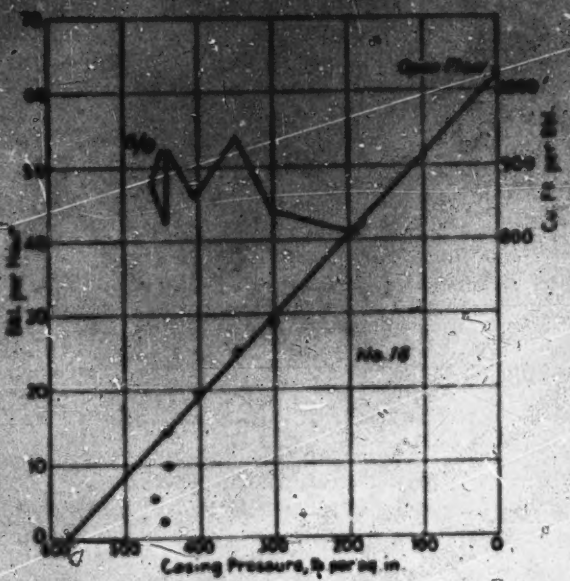


Fig. 1.—Method of determining pressure exerted by column of oil and gas at zero flow.

wells are capable of producing 2000 bbl. hourly. Gas-oil ratios are usually below 400 cu. ft. per barrel, but a few wells high on structure have produced over 3000 cu. ft. per barrel. Incidentally, tubing wells has cut these high ratios to as low as 400 cu. ft.[1] By common agreement of the operators all wells making ratios over 400 cu. ft. will be tubed. Daily production of the field is prorated to 110,000 bbl. from an open-flow potential of 5,000,000 bbl. based on hourly open-flow gages.

* Petroleum Engineer, The Texas Co.

[1] H. H. Hardison: Effects of Tubing Flowing Oil Wells. Galveston Meeting, A. P. I., Sept. 4, 1930.

The bottom-hole pressure has been determined to be 700 lb. per sq. in. gage.

Characteristic production curves for two of these wells are presented in Figs. 1 and 2. The hourly production and the gas-oil ratio are plotted against casinghead pressure. The points, excepting for very small flows, lie in a straight line. The extension of this straight line to zero pressure will give us an accurate estimate of the open flow of the well with all back-pressure removed.[1] This system of obtaining open-flow potentials without actual open-flow tests has been proposed to the operators in the Yates field.

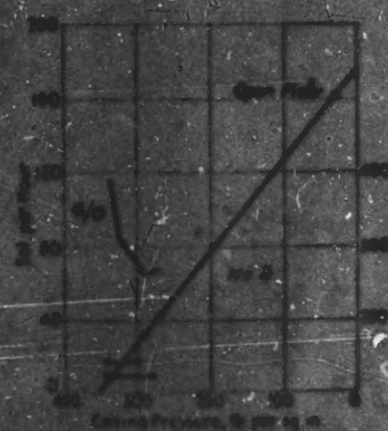


FIG. 2.—METHOD OF DETERMINING PRESSURE EXERTED BY COLUMN OF OIL AND GAS AT ZERO FLOW.

Extending the straight lines in Figs. 1 and 2 in the opposite direction to zero flow gives us a pressure value at zero flow. This pressure is interpreted to be the residual pressure after the pressure exerted by the fluid column is subtracted from the rock or bottom-hole pressure. This pressure is much more significant than a closed-in pressure, for the fluid column has not separated into its component parts, oil and gas, and the value is automatically corrected to zero flow, zero friction and zero work performed on the fluid column. The use of extrapolated values as employed in this method is in general use in engineering and scientific work and is considered applicable in this case.

The subtraction of the shut-in pressure thus found from the measured rock pressure of 700 lb. per sq. in. gives us the pressure exerted by the fluid column (× pressure). Some error is involved by the fact that flow starts somewhere back in the formation and not at measurable points such as the top of the pay or bottom of the hole. Dividing the weight of the fluid column by the distance to the point of entry to the well bore gives us the average weight per foot of the fluid column. The average density of the column can then be calculated. These were calculated on the distance to the top of the first flowing zone and the total depth of the wells.

The data from Figs. 1 and 2 are presented in Table 1; also a summary of the data used and results obtained. Some of these values are obtained from the same well by reason of different trends in different

[1] Yates Pool Committee Proposes Proration Method Based on Rock Pressure. *Pet. Engr.* (January, 1929) 1, 40.

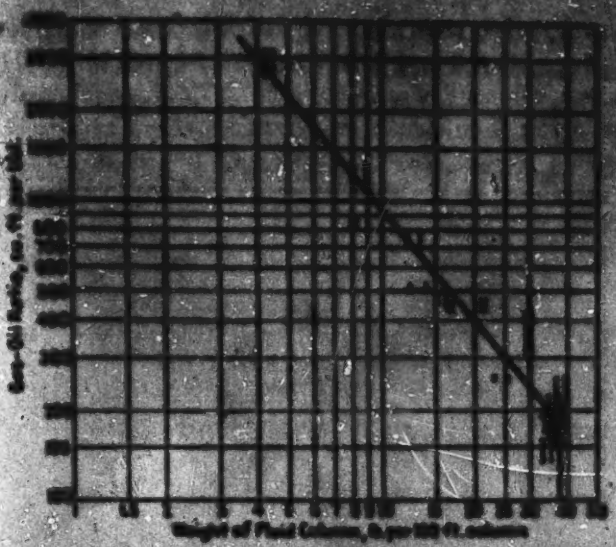


FIG. 3.—[illegible] OF FLUID CONTENTS OF VARYING GAS-OIL RATIOS.

TABLE 1.—*Summary of Well Data*

Well No.	Oil-gas Ratios	Top Pay	Total Depth	Pay Thickness	× Porosity	Calculated Recovery Per Acre-Foot, Barrels per 100 Lb.		Calculated Recovery	
						Top Pay	Total Depth	Top Pay	Total Depth
				Data from Figs. 1 and 2					
2	810– 940	1435	1510	500	150			0.195	0.183
8	250– 302	1316	1455	365	345			0.696	0.847
				Summary of Data Used and Results Obtained					
1	150– 185	1327	1462	180	330	30.2	35.1		
2	150– 200	1320	1367	500	360	29.65	34.6		
3	162– 185	1355	1568	210	480	30.1	34.35		
4	170– 200	1355	1460	320	470	30.6	35.6		
5	190– 200	1355	1460	320	470	27.2	33.6		
6	160– 225	1335	1520	320	470	29.65	35.1		
7	145– 160	1335	1520	360	430	29.65	35.1		
8	250– 302	1316	1455	365	345	29.25	29.7		
9	300– 450	1660	1680	200	310	20.5	29.6		
10	450– 600	1445	1535	405	295	16.27	15.13		
11	700– 800	1675	1844	475	235	15.47	12.20		
12	430– 470	1660	1655	475	235	21.55	21.3		
13	430– 470	1660	1655	365	175	17.0	18.6		
14	510– 530	1145	1290	365	160	13.56	12.40		
15	1150–1300	1675	1844	500	150	5.55	5.13		
16	810– 940	1435	1510	500	150	5.25	7.24		
17	2500–3240	1320	1340	640	87	4.40	4.20		

[illegible] pressure on crude oil [illegible] [illegible] with

[illegible] of gas-oil ratios, thus showing the relationship of the several values [illegible] [illegible] [illegible] 4, 5, [illegible] 6 and 7; 8, 9 and 10; 11 and 12.

The last two columns of pressures in Table 1 are plotted against the gas-oil ratios in Fig. 3 to obtain an average line. This line is terminated at the lower end by the specific gravity of the oil and the upper limit would be determined by the specific gravity of the gas.



Fig. 4.—Average pressure of [illegible] analyses of Yates sands, Penn County.

The average values found are tabulated in Table 2 and presented in Fig. 4.

Table 2.—Density of Oil-gas Columns

[illegible]	Pressure in Pounds per Square Inch	[illegible]	Per Cent. of Oil Density
[illegible]	27.0	[illegible]	100
[illegible]	27.0	[illegible]	100
[illegible]	26	[illegible]	96.3
[illegible]	25.9	[illegible]	96
[illegible]	25	[illegible]	92.6
[illegible]	25	[illegible]	92.6
[illegible]	24.7	[illegible]	91.4
[illegible]	24.6	[illegible]	91.1
[illegible]	24.6	[illegible]	91.1
[illegible]	24.5	[illegible]	90.7
[illegible]	24.4	[illegible]	90.4
[illegible]	24.4	[illegible]	90.4
[illegible]	24.4	[illegible]	90.4
[illegible]	24.4	[illegible]	90
[illegible]	24.4	[illegible]	90
[illegible]	24.3	[illegible]	90
[illegible]	24.3	[illegible]	90
[illegible]	24.3	[illegible]	90
[illegible]	24.2	[illegible]	89.6
[illegible]	24.2	[illegible]	89.6
[illegible]	24.2	[illegible]	89.6

The data show that between 160 and 200 cu. ft. of gas remain in solution in the oil under pressures of 470 to 520 lb. with very small density changes. A new curve will be found as the rock pressures decrease and less gas is kept in solution in the field underground. Similarly, a lower density would be expected were the gas-lift installed, as the gas would be in the free state at the bottom of the hole instead of in solution, as at present.

Data of this type should be of value in planning gas-lift installations and in estimating bottom-hole pressures. Each field will have its own average density curve, dependent on the depth and nature of the producing formation and the quality of the oil and gas. This method is presented in the expectation that future development and application will make it an active aid in the production of oil and gas.

DISCUSSION

(W. K. Whitford presiding)

T. V. Moore,* Houston, Tex.—Dr. Viett says that the friction losses in the lines in the Yates pool are negligible. I believe one of the curves shown was made from data taken from Humble-Smith A2. On that well, we have found that the friction losses in the formation will amount to 300 lb. per square inch or more. This shows that friction losses in the formation are very important.

Usually, a curve of well-head pressure against production is approximately a straight line at the higher rates of flow. This curve can be extrapolated to zero well-head pressure in order to determine the production under open flow, but I do not quite see Dr. Viett's reason for drawing a straight line through this curve at the lower rates of flow. It can be shown that this curve passes through a maximum point at fairly low rates of production and at lower rates will fall off materially. This type of curve has been observed not only in lime fields but also in fields where the production is taken from unconsolidated sands. Thus, it does not seem to be justifiable to assume that the curve of well-head pressure against production is a straight line at all rates of flow. Experimental work which we have carried on with the gas-lift shows that the average density of a column of oil and gas is dependent as much on the quantity of gas flowing as on the gas-oil ratio. At lower rates of flow, the density of the oil-gas mixture approaches that of the liquid, while at the higher rates the density of the mixture falls off materially. Therefore, the density depends not alone on gas-oil ratio but also on rate of production.

W. V. Vuyet.—Mr. Moore's suggestions are valid inasmuch as the rate of flow does affect the average density of the fluid column. *Low* rates of flow occur when high back-pressures are applied. *Friction* and work are at a minimum; the high pressure causes the oil to retain most of the gas and thus the density of the column approaches that of gas-free oil. Movement of the fluid column is slight and gravity separation of gas and oil occurs. Under higher rates of flow, it is taken for granted that the fluid at the bottom of the column contains little or no free gas, and that the free gas content increases as the fluid nears the top of the hole.

The extrapolation of the straight line back to zero flow does not assume that a well will flow with straight-line characteristics in this region of flow. Friction and

* Production Research Engineer, Humble Oil & Refining Co.

[redacted]

[redacted] decrease as the well-head pressure is reduced [redacted]. The pressure drop between [redacted] and the bottom of the hole is the difference between the well-head pressure and the bottom-hole pressure. [redacted] the density of the fluid column under static [redacted] conditions. [redacted] is made to the flow or densities being valid for low rates of flow under high bottom-hole pressures.

The formation in the Yates field is valuable in character and the flow through the formation is more or less of the same nature as that through the flow string. There are two errors in the method mentioned: (1) We do not know the average distance to the point of fluid entry; (2) the well fluid contains much gas in solution under high pressure. There are gases involved but I do not believe that the method is vitiated by the values actually found under low rates of flow where the back-pressure is keeping practically all of the gas in solution; gravitational separation is assuming and stable conditions exist. Under these conditions, the density of the fluid column approaches that of the oil.

T. V. Moore.—There is a very definite reason why that curve passes through a maximum. Pressure losses in the sand increase regularly with production rate. Pressure losses in the flow string at low production rates tend to decrease as production is increased. At higher production rates, friction loses become more important and the pressure losses in the flow string increase with increase in production because the increased friction losses offset the lightening of the columns of fluid. The sum of the pressure losses in the flow string and the pressure losses in the sand is, of course, the combined pressure losses from the interior of the reservoir to the well head. It is readily seen that this curve passes through a minimum point which corresponds to the maximum point on the curve of well-head pressure. This is the reason why the curve of well-head pressures rises to a maximum and then falls off.

DEFENDANT'S EXHIBIT L

390

Department of Commerce
United States Patent Office

To all persons to whom these presents shall come,
Greeting:

This Is To Certify that the annexed is a true copy from the records of this office of the Fire Wrapper and Contents, in the matter of the

Pending Application of
Cranford P. Walker,
Filed September 18, 1937, Serial Number 164,534,
for
Improvement in Vibration Translating Means.

In Testimony Whereof I have hereunto set my hand and caused the seal of the Patent Office to be affixed at the City of Washington, this twenty-seventh day of March, in the year of our Lord one thousand nine hundred and forty-two and of the Independence of the United States of America the one hundred and sixty-sixth.

(Seal)

CONWAY P. COE
Commissioner of Patents.

Attest:

D. E. WILSON
Chief of Division.

954

PATENT NO.

1937

DATED

(EX'R'S BOOK)

17-13

RENEWED

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Defendant's Exhibit L—(Continued)

Mail Division Sep 18 1937 U. S. Patent Office.
Sep 1 18 - 37 051516 D—Check—30.00.

Harold W. Mattingly
Attorney at Law
Patent and Trademark Causes
924 Pacific Finance Building
621 South Hope Street
Los Angeles, California
MAdison 1137
1/84

September 13, 1937.

Commissioner of Patents,
Washington, D. C.

Sir:

Attached is application for Letters Patent of the United Sattes executed September 4, 1937 by Cranford P. Walker for Vibration Translating Means; also attached is my check No. 218 in the amount of $30.00 to cover the Government filing fee (20 claims).

Respectfully,
HAROLD W. MATTINGLY

MM

1/84

Mail Division Sep 18 1937 U. S. Patent Office.
Received Sep 29 1937 Division 5, Paper No.

Defendant's Exhibit L—(Continued)

PETITION

To the Commissioner of Patents:

Your petitioner, Cranford P. Walker, a citizen of the United States, residing at San Marino, in the County of Los Angeles, and the State of California, whose post office address is 2824 Carlaris Road, San Marino, California, prays that Letters Patent may be granted to him for the Vibration Translating Means set forth in the annexed specification, and he hereby appoints

Harold W. Mattingly
924 Pacific Finance Building
621 South Hope Street
Los Angeles, California
(Registry No. 12,385)

his attorney, with full power of substitution and revocation, to prosecute this application, to make alterations and amendments therein, to receive the patent and to transact all business in the Patent Office connected therewith.

(Sign here first name in full)

CRANFORD P. WALKER

SPECIFICATION

To All Whom It May Concern:

Be It Known, That I, Cranford P. Walker, a citizen of the United States, residing at San Marino, in the County of Los Angeles, and State of California, have invented certain new and useful

Defendant's Exhibit L—(Continued)

improvements in Vibration Translating Means of which the following is a specification:

1/2

My invention relates to vibration translating means and has particular reference to the reception and translation of pressure waves such as are produced in the echo type of well surveying instruments, to translate the character, form and shape of the received waves or vibrations into graphs or records which may permit the observance and study of the shape, form or character of these waves.

In the measurement of well depths and the location and determination of obstructions of various characters in wells, particularly oil wells, by the pressure wave echo method, a pressure impulse is created in the well, which impulse travels down the well to the various obstructions or constrictions found in the well and is partially reflected by each of them, the reflected waves or echoes traveling back up the well to operate some suitable pressure responsive device which moves or vibrates in response thereto in accordance with the character, amplitude and form of the wave. The echoes or reflections from various different objects encountered within the well produce distinct pressure-time wave patterns for each of the objects or reflecting surfaces and it is desirable to reproduce these wave patterns so that their character, shape, form and relative amplitudes may be observed and studied in order to properly in-

Defendant's Exhibit L—(Continued)

terpret them in terms of nature and character of the reflecting or obstructing devices.

These pressure waves or echoes may be received at the ground surface by mechanical or electrical pressure responsive devices, such as mechanical diaphragms or electrical microphones. It is difficult to construct mechanical receiving devices which will respond with sufficient sensitivity and accuracy to reproduce all of the minute variations in the shape of the wave patterns and conventional electrical microphones, and amplifiers, due to their inability to function with any degree of fidelity where the frequency is below the audible range, have also been found to be inadequate to correctly and completely reproduce the wave patterns in such form as to permit the ready and complete study of the wave patterns.

It is therefore an object of my invention to provide a pressure responsive device which may be used for the reception and translation of the pressure waves, or echoes ~~or other vibrations~~ to accurately reproduce ^ pressure—time wave patterns corresponding in detail with the wave patterns of the ^ pressure wave or echoes. ~~vibrations.~~

Another object of my invention is to provide a pressure responsive device for the reception and translation of vibrations of the character set forth which is extremely sensitive and which faithfully reproduces a wave pattern corresponding to the wave pattern of the vibrations.

Defendant's Exhibit L—(Continued)

Another object of my invention is to provide an electrical system for receiving pressure waves, echoes or other vibrations of the character set forth in which minute variations or changes in the wave patterns described by the vibrations may be received, observed and recorded.

Another object of my invention is to provide a system of the character set forth in the preceding paragraph wherein a novel microphone capable of varying its ∧ electrical impedance is placed in a high frequency tuned circuit adapted to produce a high frequency wave in the nature of a carrier wave and in which the microphone modulates the high frequency current which is then amplified and rectified to operate a direct current galvanometer, oscillograph or other suitable device for accurately indicating and recording the ∧ pressure variations ~~vibrations~~ received by the microphone.

Other objects and advantages of my invention will be apparent from a study of the following specifications, read in connection with the accompanying drawings, wherein

Fig. 1 is a diagrammatic view illustrating the adaptation of my vibration translating mechanism associated with a pressure wave echo well surveying system;

Fig. 2 is a diagrammatic view of one form of electrical circuit which may be employed to translate the pressure variations received ∧ ~~vibrations~~ into observable ∧ pressure-time ~~wave~~ patterns or records;

Defendant's Exhibit L—(Continued)

Fig. 3 is a composite diagrammatic view illustrating the character of the wave patterns which may be reproduced upon a recording chart, compared with the characteristics of the direct current output circuit in accordance with changes in the air gap of the microphone employed in my system;

Fig. 4 is a diagrammatic view of a modified type of circuit which may be employed in the practice of my invention; and

Fig. 5 is a diagrammatic view of a still further modified circuit which may be employed.

Referring to the drawings, I have illustrated my translation system as being associated with a pressure wave echo well surveying device which has now issued as United States Letters Patent No. 2,156,519. such as that illustrated and claimed in my copending application Serial No. 162,699, Filed September 7, 1937.

In Fig. 1 I have illustrated an oil well 1 lined with the usual casing 2 which extends from the ground surface 3 to the bottom of the well. A pump 4 may be located at any desired depth in the well, the pump 4 being usually suspended upon a string of oil flow tubing 5 through which a string of sucker rods 6 extends to operate the moving part of the pump 2, the string of oil flow tubing 5 being usually constructed of a plurality of assembled sections of tubing coupled together by means of couplings 7. A tubing catcher 8 is usually disposed in the string of oil flow tubing. The pump 4 is usually secured to the lower end of the tubing string and lies within a perforated liner 9.

Defendant's Exhibit L—(Continued)

In making a survey to determine the location and character of any of a plurality of obstructions or constrictions of the cross sectional area of the casing 2 or enlargement of the well bore where it is not cased, a pressure impulse of any desired intensity may be introduced into or created within the well casing 2, preferably by either suddenly introducing into the well casing 2 a volume of gas at a pressure higher than the normal gas pressure within the casing 2 or allowing the sudden escape of a volume of the normal gas within the well to create a rarefaction impulse. The method and apparatus for creating the pressure impulse is described in my copending application hereinbefore referred to as consisting essentially of a pressure chamber 10 coupled through a quick opening valve 11 and a pipe 12 to the interior of the casing 2, the pressure chamber 10 being adapted to receive a volume of gas from a suitable tank or source of supply 13 through a ~~quick opening~~ valve 14 until the pressure within the chamber 10 has been built up to a desired value in excess of the value of the normal gas pressure within the casing 2. By then closing valve 14 and quickly opening valve 11, the gas within the chamber 10 may be suddenly released into the casing 2 and create a pressure impulse therein, which impulse partially travels as a pressure wave down the casing 2 and is ^ reflected back by each of the various obstructions within the well, (^C[1]) [Note in margin: Mrs. Scott note that this insertion is D[1]] ~~including the tubing~~

Defendant's Exhibit L—(Continued)

~~collars 7, the tubing catcher 8, and the surface 15 of the fluid within the well, and the top of the liner 9.~~

The pressure impulse and pressure wave may also be created by closing valve 14, opening valve 11 to allow the normal gases within the well to pass into the chamber 10, then closing valve 11 and opening valve 14 to exhaust the gases in the chamber 10 until the pressure therein reaches any predetermined value lower than the pressure within the well. By closing valve 14 and then reopening valve 11 quickly, a volume of the confined gas within the well is allowed to enter the chamber 10, creating a rarefaction impulse which travels down the well and back in the same manner as described for the introduction of pressure into the well.

The reflected impulses or waves, returning up through the casing 2, pass through the pipe 12 to a pressure responsive device 16 which includes a diaphragm 17 exposed to the pressures within the casing 2.

The pressure responsive device in this form of the invention ∧ constituted by ~~constitutes~~ a condenser type microphone, the diaphragm 17 being constructed of a relatively thin sheet of duralumin, the outer edges of which are clamped between a pair of housing members 18 and 19. Disposed in the housing 19 is a mounting block 20 of insulating material, one face of which carries the opposite electrode of the condenser microphone, this electrode being illustrated as a cup-

Defendant's Exhibit L—(Continued)

shaped member 21 of duralumin, the outer face of which is disposed parallel to the plane of the diaphragm 17 and spaced in relatively close juxtaposition thereto.

The housing member 19 forms with the diaphragm 17 a closed chamber 22 and, in order to make the diaphragm 17 sensitive to minute variations in pressure within the casing 2, I prefer to equalize the static pressure within the pipe 12 on both sides of the diaphragm 17 as by providing a somewhat restricted by-pass 23 communicating with the interior of the housing member 18 and with the chamber 22, a suitable filter 24 being interposed in the by-pass if desired to filter and dry the gases to prevent undue corrosion of the parts. A plurality of openings 25 are preferably provided through the electrode 21 and its supporting member 20 to avoid the building up of undesirable pressures between the diaphragm 17 and the electrode 21 by fluctuations of the diaphragm.

The diaphragm 17 may be grounded as indicated at 26 and the electrode 21 may be connected by a suitable wire 27 to an oscillator-amplifier-rectifier indicated generally at 28 and hereinafter more fully described, the output of which may be coupled as indicated at 29 to any suitable indicating or recording device indicated generally at 30. The indicating and recording device may be a recording galvanometer, oscillograph or other suitable device illustrated diagrammatically in Fig. 1 as including a galvanometer 31 which may be arranged to oscillate a mirror

Defendant's Exhibit L—(Continued)

32 receiving light from a suitable source 33 and directing the reflected beam 34 thereof upon a recording tape 35 or upon a suitable screen 36 where the pressure-time movements of the beam, that is, the ∧ wave pattern ~~transmitted by the diaphragm~~, may be observed, studied or recorded.

In the system diagrammatically illustrated in Fig. 1, the light beam 34 has a ribbon-like shape, a reflecting mirror 37 being interposed to intercept a portion of the beam and direct the same through a cylindrical condensing lens 38 upon the screen 36 while the remaining portion of the beam 34 passes through a suitable cylindrical condensing lens 39 to convert the same into a point beam where it may describe the wave pattern upon the tape 35. The tape 35 may be moved relative to the beam 34 in any suitable manner as by a variable speed motor 40 controlled by a rheostat or other device 41.

In view of the fact that the determination of the location of the various obstructions encountered by the pressure wave is made by comparing the wave pattern produced by the echoes from the various obstructions with relation to the time lapse between the creation of the pressure impulse in the casing 2 and the arrival of the echoes at the diaphragm 17, I prefer to describe upon the recording tape 35 a pattern of time lapse indications. One manner in which the same can be done readily is indicated in Fig. 1 as including a synchronous motor 42 arranged to drive an opaque disc 43 having a plurality

Defendant's Exhibit L—(Continued)

of openings 44 therethrough aligned with a light beam 45 from the same light source 33 as was used to produce the beam 34, the openings 44 in the disc being arranged in such manner that during a predetermined time cycle a plurality of dots or marks will be produced by the beam 45 upon the record chart 35, one of the openings 44a being preferably larger than the remainder to make distinguishing marks upon the tape 35 indicitive of the lapse of a multiple of the time units.

With the system just described, the vibrations or movements of the diaphragm 17 relative to the electrode 21 may be utilized to draw upon the chart 35 a faithful wave pattern corresponding to the wave pattern of the echoes received from each of the obstructions in the well, not only the large variations in the pressure but the minute variations thereof which changes the character of the wave form or wave shape.

I prefer the translation mechanism indicated diagrammatically in Fig. 2 as comprising an electrical circuit including a relatively high frequency oscillator circuit A, a tuned amplifier circuit B in which the microphone 17-21 is interposed, an ordinary amplifier circuit C and a rectifier circuit D, producing a direct current output which may be fed

30

directly into the galvanometer 31 or other oscillograph or recording apparatus capable of responding to direct current variations.

Defendant's Exhibit L—(Continued)

In Fig. 2 I have illustrated the oscillator circuit as including an ordinary vacuum tube 50, the grid circuit of which includes a coil 53 and a variable condenser 54 by which the circuit A may be tuned to oscillate at any declared frequency, preferably a moderately high frequency, ranging from approximately 10,000 cycles to 100,000 or more cycles per second, a blocking condenser 54a and a stabilizing resister 54b connecting the grid circuit to the plate circuit in the usual manner.

The output of the tube in circuit B is coupled as indicated at 55a to a standard amplifier circuit C, the microphone 17-21 being included in this circuit and so connected that variations in the air gap between the diaphragm 17 and the electrode 21 will act as a variable condenser. A pair of variable condensers 56 is included in the circuit, one in series with the microphone 17-21, the other in shunt circuit relation to both the microphone 17-21 and the other of these variable condensers and so coupled together that an increase in the ~~reactance~~ capacitance of one of the condensers is accompanied by decrease in the capacitance ~~reactance~~ of the other, ~~the condensers 56 being adjusted to vary the sensitivity of response of the microphone 17-21, as hereinafter more fully described, without changing the tuning of the circuit B.~~ (D^2) A rectifier circuit D, constituting a full wave rectifier, is coupled to the output of the amplifier circuit ~~D~~ C while a direct current measuring or

Defendant's Exhibit L—(Continued)

recording instrument 30 is connected to be supplied with current from the rectifier D. (∧D^3) ~~A variable inductor 57 is included in the output of the circuit B to tune or detune the circuit B to vary the normal steady direct current output from the rectifier to centralize the light beam 34 on the chart 35.~~

output of

The ∧ circuit ∧ B is normally detuned relative to the output frequency of the oscillator A so that variations in the air gap of the microphone 17-21 will tend to tune the circut B or to further detune the same. By tuning the circuit B until the output of the rectifier circuit D is approximately one-half maximum, as indicated by the point g in Fig. 3, on the curve plotted by the direct current output in milliamperes against microphone air gap varia-

straight

tion, the ∧ light beam will describe a line on the chart 35 when the pressure in the well casing 2 is static; that is, the line y on the chart 35 represents the normal position of the beam when no pressure variations are being transmitted to the diaphragm

negative

17. However, a ~~positive~~ ∧ pressure wave striking

open

the diaphragm 17 will ~~close~~ ∧ the air gap of the microphone 17-21, tuning the circuit B closer to the frequency of the oscillator and permitting a higher direct current output in the rectifier D and causing the light beam 34 to describe a peak or wave pattern y^1, the shape and amplitude of which is in correspondence with the shape and amplitude of the wave pattern effecting the microphone. Simi-

Defendant's Exhibit L—(Continued)

positive
larly, a ∧ ~~negative~~ impulse striking the diaphragm 17 will cause a further detuning of the circuit B

deflection
and cause a ∧ ~~fluctuation~~ of the light beam to describe a peak y^{11}. The circuits are so proportioned that the maximum positive and negative deflections of the diaphragm 17 will describe a pattern within

straight line
portion of the
the limits of the points a and b on the ∧ curve x,

lying
that is, ~~lighting~~ ∧ between the limits indicated by dotted lines 58 and 59 on the chart 35.

By properly tuning the circuits A and B, the recorder or indicating instrument 30 may be caused to describe an observable wave pattern identical with the wave pattern received from the various obstructions in the well.

A modified form of circuit which may be employed is indicated in Fig. 4 wherein the microphone 17-21 is inserted in the oscillator circuit A so that any variation in the air gap in the microphone 17-21 varies the output frequency of the oscillator circuit A. The oscillator circuit A is illustrated as being coupled to a tuned amplifier circuit B which will pass more or less current to the rectifier D as the output frequency of the oscillator

resonant
circuit A approaches the ∧ ~~tuned~~ frequency of the circuit B or recedes therefrom. Again the indicating or recording instrument 30 is connected to the

Defendant's Exhibit L—(Continued)

output of the rectifier circuit D to be varied by the direct current output of this circuit.

In Fig. 5 I have illustrated a still further modified circuit which may be employed including a balanced alternating current circuit A which includes an alternating current generator 60 which may be of either the rotary or oscillator type, the output of which is ∧ may be of any desired relatively high frequency, ∧ is coupled to a balanced bridge rectifier circuit E including a pair of half wave rectifier tubes 61 and 62, the tube 61 being connected in one branch of the bridge including the secondary winding of a transformer 63 while the tube 62 is in the other branch including the secondary of the transformer 64. The primary circuit of the transformer 64 includes a variable impedence 65, permitting this circuit to be varied to balance the normal current in the two branches of the bridge, while the primary winding of the transformer 63 is in series with variable impedances 66 and with the microphone 17-21. The recorder or indicator 30 in this form of the device is connected in a shunt circuit extending between the junction of the secondary windings of the transformers 63-64 and the junction between the two rectifiers 61-62.

In this form of the device, when the ∧ combined effect of the impedances of the microphone 17-21 and ∧ its associated variable impedances 66 is equal to that of the variable

Defendant's Exhibit L—(Continued)

impedance 65 ~~are equal~~, the secondary voltages of the transformers 63-64 are equal and there is no potential impressed across the indicator or recorder 30. Any slight variations in the supply voltage or in the frequency supplied by the generator 60 will affect therefore be balanced and will not ∧ ~~effect~~ or be recorded by the recorder 30. A pressure wave or signal impinging upon the diaphragm 17 varies the impedance ∧ ~~thereof,~~ of the microphone 17-21 which in turn unbalances the secondary voltage of the two transformers, resulting in a voltage across the direct current recorder, the direction of which will depend upon whether the impedance of the microphone has been increased or decreased by the signal. (D⁴) The variable condensers 66 may be employed for varying the sensitivity of the microphone without changing the current passing through the transformer 63; that is, the condensers 66 should be so arranged that any increase in the impedance of one is balanced by a corresponding decrease in the impedance of the other.

In each of the circuits described, a reactor 68 and condensers 69 and 70 may be interposed in any portion of the circuits between the microphone and the galvanometer; for example, in the direct current output circuit, if desired, for filtering or for accenting tuning the recorder circuit for the purpose of ∧ periodically recurring ~~amplifying~~ certain of the ∧ echoes received from certain of the obstructions in the well, such as the

Defendant's Exhibit L—(Continued)

echoes received from the tubing colalrs, the frequency of which ranges from 14 to 36 cycles per second. (∧D5) ~~Also, one or more stages of amplification may be added in advance of the recorder 30 for the purpose of amplifying the signals received sufficiently to give a desired fluctuation of the recorder.~~

Patent No. 2,156,519

As is described and claimed in my ∧ ~~copending application~~ hereinbefore referred to, it is important to determine the pressure wave velocity in the particular well under measurement, this velocity being arrived at very readily if the location of one or more of the obstructions in the well is known. Where the location of these obstructions is not known, the velocity of the pressure wave through the particular gaseous medium in the particular well may be readily determined by passing gas from the well casing 2 through a velocity measuring tube 80 as by coupling one end of the tube 80 to the pipe 12 as by means of a pipe 81, the opposite end of the tube 80 being open to the atmostphere as indicated at 82, suitable valves being interposed in the inlet and outlet of the tube 80 to regulate the flow of gas therethrough.

At one end of the tube 80 I provide a diaphragm 83, preferably of magnetic material or in some manner arranged to be vibrated by alternating current supplied to a magnet 84. The alternating current may be supplied through a suitable generator 85 driven by a variable speed motor 86 controlled as to speed by means of a suitable rheostat 87 and pro-

Defendant's Exhibit L—(Continued)

vided with a revolution counter 88 or other indicator which will produce an indication of the frequency of current output of the generator 85 under variable speeds of operation of the motor 86. The voltage and current output of the generator 85 may also be variably controlled as by a rheostat 89.

By supplying current to the magnet 84, the diaphragm 83 may be vibrated at any desired frequency to produce pressure impulses in the tube 80 which will travel along the tube, engaging a diaphragm 17a of a standard microphone or a special microphone similar to microphone 17-21 hereinbefore described. By selecting the frequency of the output of the generator 85 such that a pressure impulse created by the diaphragm 83 will pass to the diaphragm 17a of the microphone and return to the diaphragm 83, synchronized with the production of another impulse by the diaphragm 83, the resulting resonance produced in the tube 80 with the particular gas from the well flowing therethrough may be noted upon a suitable output meter or oscillograph 90, the microphone 17a being coupled through a suitable oscillator-amplifier-rectifier circuit, indicated diagrammatically at 91, similar to any one of those illustrated in Figs. 2, 4 and 5 or through a standard radio type of amplifier. By noting the frequency applied to the diaphragm 83 to obtain resonance and the frequency necessary to apply to the diaphragm 83 to obtain resonance in the tube 80 with air flowing therethrough, a computation of the velocity of

Defendant's Exhibit L—(Continued)

pressure waves in the particular gaseous medium in the well may be readily determined.

While I have illustrated and described herein a condenser type microphone, it will be understood by those skilled in the art that any type of microphone, the impedance of which is varied by the signal or pressure impulses received ~~upon the diaphragm 17~~ thereupon, may be employed.

While I have shown and described the preferred embodiment of my invention, I do not desire to be limited to any of the details of construction shown or described herein, except as defined in the appended claims.

HWM:MM

I CLAIM:

~~1. In a system for producing an observable wave~~ pattern corresponding to an energy wave, a high frequency electric circuit, means in said circuit for receiving the energy wave and for varying the intensity of current in said high frequency circuit in accordance with the wave pattern of said energy wave, means for rectifying the high frequency alternating current into direct current, and a direct current translating device in the output circuit of said rectifier for graphically describing a wave pattern corresponding to the pattern of said energy wave.

2. In a system for receiving and transmitting pressure echoes from a well, a microphone adapted to vary its impedance in correspondence with pressure variations impinging thereon, means for cou-

Defendant's Exhibit L—(Continued)

pling said microphone to said well to expose said microphone to the gas pressures in the well, a source of high frequency current, a high frequency circuit (curre , means coupling said microphone in said high equency circuit to vary the current output of said circuit, and translating means for receiving the output of said circuit and for describing an observable wave pattern described by said output current variation.

3. In a system for receiving and translating pressure echoes from a well, a microphone adapted to vary its impedance in correspondence with pressure variations impinging thereon, means for coupling said microphone to said well to expose said microphone to the gas pressures in the well, a source of high frequency current, a high frequency circuit, means coupling said microphone in said high frequency circuit to act as tuning means tending to tune and detune said circuit relative to said frequency as it is affected by said echoes, to thereby vary the current output of said circuit, and translating means for receiving the output of said circuit and for describing an observable wave pattern described by said output current variation.

4. In a system for receiving and translating pressure echoes from a well, a microphone adapted to vary its impedances in correspondence with pressure variations impinging thereon, means for coupling said microphone to said well to expose said microphone to the gas pressures in the well, a source

Defendant's Exhibit L—(Continued)

of high frequency current, a high frequency circuit, means coupling said microphone in said high frequency circuit to act as tuning means tending to tune and detune said circuit relative to said frequency as it is affected by said echoes, to thereby vary the current output of said circuit, additional tuning means in said high frequency circuit for varying the sensitivity of said circuit to the tuning effects of said microphone, and translating means for receiving the output of said circuit and for describing an observable wave pattern described by said output current variation.

5. In a system for receiving a translating pressure echoes from a well, a microphone adapted to vary its impedance in correspondence with pressure variations impinging thereon, means for coupling said microphone to said well to expose said microphone to the gas pressures in the well, a source of high frequency current, a high frequency circuit, means coupling said microphone in series with the output circuit of said high frequency circuit to act as tuning means tending to tune and detune said circuit relative to said frequency as it is affected by said echoes, to thereby vary the current output of said circuit, and a pair of impedances inversely variable relative to each other, one in series with said microphone and the other shunted across both said microphone and said first impedance, and translating means for receiving the output of said circuit and for describing an observable wave pattern described by said output current variation.

Defendant's Exhibit L—(Continued)

6. In a system for graphically describing an observable wave pattern of a plurality of echoes received from a plurality of different obstructions in a well to permit the ready distinguishment of the echoes received from different obstructions, a microphone the impedance of which is varied by and in accordance with energy waves impinging thereupon, means coupling said microphone to said well to expose said microphone to the pressure waves existing in said well, a high frequency electric circuit, means coupling said microphone to said circuit to vary the intensity of current in said circuit in accordance with vibrations received by said microphone, means for rectifying the output current from said circuit, a direct current translating device coupled to the output of said rectifier for graphically describing a pattern of the waves impinging on said microphone, and means in said high frequency circuit for adjusting the natural period of oscillation of said circuit to produce a direct current output from said rectifier approximately midway between maximum and minimum values when said microphone is subjected only to static pressures.

7. In a system for graphically describing an observable wave pattern of a plurality of echoes received from a plurality of different obstructions in a well to permit the ready distinguishment of the echoes received from different obstructions, a microphone the impedance of which is varied by and in accordance with energy waves impinging thereupon, means coupling said microphone to said well to ex-

Defendant's Exhibit L—(Continued)

pose said microphone to the pressure waves existing in said well, a high frequency electric circuit including said microphone and means for tuning said circuit, means for amplifying and rectifying the current in said high frequency circuit, and a direct current translating device for graphically describing a pattern of the waves impinging on said microphone, whereby adjustment of said tuning means produces a steady direct current output approximately midway between maximum and minimum values when said microphone is subjected to static pressures.

8. In a system for graphically describing an observable wave pattern of a plurality of echoes received from a plurality of different obstructions in a well to permit the ready distinguishment of the echoes received from different obstructions, a microphone the impedance of which is varied by and in accordance with energy waves impinging thereupon, means coupling said microphone to said well to expose said microphone to the pressure waves existing in said well, a high frequency electric circuit including inthe output circuit thereof a reactor, a tuning condenser and said microphone in series relation with each other, and a second tuning condenser connected in series relation with said reactor but in shunt relation across both said microphone and said first condenser, a rectifier for rectifying the output current from said circuit, a direct current translating device coupled to the output of said rectifier for

Defendant's Exhibit L—(Continued)

graphically describing a pattern of the waves impinging on said microphone, and means in said high frequency circuit for adjusting the natural period of oscillation of said circuit to produce a direct current output from said rectifier approximately midway between maximum and minimum values when said microphone is subjected only to static pressures.

9. In a system for graphically describing an observable wave pattern of a plurality of echoes received from a plurality of different obstructions in a well to permit the ready distinguishment of the echoes received from different obstructions, a microphone the impedance of which is varied by and in accordance with the energy waves impinging thereupon, means coupling said microphone to said well to expose said microphone to the pressure waves existing in said well, a high frequency electric circuit having tuning means therein, means connecting said microphone in said high frequency circuit to tune or detune said circuit in accordance with variations of impedance in said microphone, rectifying means for rectifying the output current in said circuit, and a direct current translating device for graphically describing a pattern of the waves impinging on said microphone.

10. In a system for graphically describing an observable wave pattern of a plurality of echoes received from a plurality of different obstructions in a well to permit the ready distinguishment of

Defendant's Exhibit L—(Continued)

the echoes received from different obstructions, a microphone the impedance of which is varied by and in accordance with the energy waves impinging thereupon, means coupling said microphone to said well to expose said microphone to the pressure waves existing in said well, a high frequency electric circuit, means for connecting said microphone in said high frequency circuit to tune or detune said circuit in accordance with variations of impedance in said microphone, rectifying means for rectifying the output current in said circuit, and tuning means in said high frequency circuit adjustable to detune said circuit approximately midway between the tuning and detuning limits thereof by the microphone.

11. In a system for graphically describing an observable wave pattern of a plurality of echoes received from a plurality of different obstructions in a well to permit the ready distinguishment of the echoes received from different obstructions, a microphone the impedance of which is varied by and in accordance with the energy waves impinging thereupon, means coupling said microphone to said well to expose said microphone to the pressure waves existing in said well, a high frequency electric circuit, means for connecting said microphone in said high frequency circuit to tune or detune said circuit in accordance with variations of impedance in said microphone, rectifying means for rectifying the output current in said circuit, tuning means in said high frequency circuit adjustable to detune said cir-

Defendant's Exhibit L—(Continued)

cuit approximately midway between the tuning and detuning limits thereof by the microphone, and one or more stages of amplification interposed between said high frequency circuit and said rectifier.

12. In a system for graphically describing an observable wave pattern of a plurality of echoes received from a plurality of different obstructions in a well to permit the ready distinguishment of the echoes received from different obstructions, a microphone the impedance of which is varied by and in accordance with the energy waves impinging thereupon, means coupling said microphone to said well to expose said microphone to the pressure waves existing in said well, a high frequency electric circuit, means for connecting said microphone in said high frequency circuit to tune or detune said circuit in accordance with variations of impedance in said microphone, ^ full wave rectifying means for rectifying the output current in said circuit, tuning means in said high frequency circuit adjustable to detune said circuit approximately midway between the tuning and detuning limits thereof by the microphone, and one or more stages of amplification interposed between said high frequency circuit and said full wave rectifier.

13. In a system for graphically describing an observable wave pattern of a plurality of echoes received from a plurality of different obstructions in a well to permit the ready distinguishment of the echoes received from different obstructions, a micro-

Defendant's Exhibit L—(Continued)

phone the impedance of which is varied by and in accordance with the energy waves impinging thereupon, means coupling said microphone to said well to expose said microphone to the pressure waves existing in said well, a high frequency electric circuit having tuning means therein, rectifying means for rectifying the output current of said circuit, a high speed direct current galvanometer coupled to said rectifier to be actuated by the direct current output thereof, and means actuated by said galvanometer to describe a pattern of the waves impinging on said microphone.

14. In a system for receiving and translating pressure echoes from a well, a microphone adapted to vary its impedance in correspondence with pressure variations impinging thereon, means for coupling said microphone to said well to expose said microphone to the gas pressures in the well, a source of high frequency current, a high frequency circuit, means coupling said microphone in said high frequency circuit to act as tuning means tending to tune and detune said circuit relative to said frequency as it is affected by said echoes, to thereby vary the current output of said circuit, translating means for receiving the output of said circuit and for describing an observable wave pattern described by said output current variation, and variable filter means interposed between said microphone and said translating means for amplifying response thereof to desirable pressure echoes and minimizing others.

Defendant's Exhibit L—(Continued)

15. In a system for receiving and translating pressure echoes for various obstructions in a well, pressure responsive means coupled to the well to be exposed to pressure variations therein, electrical means actuated by said pressure responsive means to vary electrical values in accordance with the variations of pressure received by said pressure responsive means, translating means for receiving said electrical variations and for describing an observable wave pattern corresponding to the patterns of the echo waves, and means interposed between said pressure responsive means and said translating means for tuning said electrical means to respond more readily to echoes from selected obstructions than to pressure variations emanating from other sources.

16. In a system for receiving and translating pressure echoes from a well, a microphone adapted to vary its impedance in correspondence with pressure variations impinging thereon, means for coupling said microphone to said well to expose said microphone to the gas pressures in the well, a source of high frequency electrical current, means coupling said microphone to said source to vary the frequency in accordance with variation in the pressures impinging thereon, a high frequency amplifier circuit coupled to said source, a rectifier coupled to said amplifier and a direct current translating device in the output circuit of said rectifier to graphically describe a wave pattern corresponding to the pattern of the echo pressure waves, and means for tun-

Defendant's Exhibit L—(Continued)

~~ing said amplifier to the frequency of said source~~ when said microphone ~~is subject~~ only to static pres-~~sure.~~

17. In a system for receiving and translating pressure echoes from a well, a microphone adapted to vary its impedances in correspondence with pressure variations impinging thereon, means for coupling said microphone to said well to expose said microphone to the gas pressures in the well, ~~a source of high frequency current,~~ a balanced bridge circuit including a half wave rectifier in each branch thereof, and a direct current translating device connected across said branches for receiving the unbalanced output of said rectifiers and for describing therefrom a wave pattern corresponding to the pattern of the pressure waves received upon said microphone, ($\wedge B^1$) means coupling said ~~high~~ frequency source to each of said branches, and means interposing said microphone in the coupling to one branch whereby said bridge circuit will be unbalanced in accordance with variations in said pressure waves.

~~18.~~ In a system for determining pressure wave velocity in a given medium, an elongated tube, means for passing the said medium through said tube, means for creating pressure waves in said tube of known frequency including a diaphragm exposed to the interior of said tube, magnetic means for vibrating said diaphragm, a source of variable frequency electric current supplying said magnet,

Defendant's Exhibit L—(Continued)

means for determining the frequency at which said tube resonates including a second diaphragm exposed to the interior of said tube and spaced from said first diaphragm, said diaphragm comprising one element of a microphone, and electrical means for translating vibrations of said second diaphragm in terms of electrical current variations, translating means for receiving said current variations and for describing an observable pattern corresponding to the vibrations received by said second diaphphragm.

~~10.~~ In a system of determining pressure wave velocity in a given medium, an elongated tube, means for passing the said medium through said tube, means for creating pressure waves in said tube of known frequency including a diaphragm exposed to the interior of said tube, magnetic means for vibrating said diaphragm, a source of variable frequency electric current supplying said magnet, means for determining the frequency at which said tube resonates including a second diaphragm exposed to the interior of said tube and spaced from said first diaphragm, said diaphragm comprising one element of a microphone, and electrical means for translating vibrations of said second diaphragm in terms of electrical current variations, translating means coupled to said microphone including a galvanometer movable in correspondence with said current variations, and means for describing an ob-

Defendant's Exhibit L—(Continued)

~~servable pattern of the movements of said galvan-~~ometer.

~~20.~~ A vibrating translating means substantial~~ly as described and shown.~~

Add B^2 C^1 C^7

1/84

In testimony whereof I affix my Signature.

(Sign here first name in full)

CRANFORD P. WALKER

OATH

State of California

County of Los Angeles—ss.

Cranford P. Walker, the above named petitioner, being duly sworn, deposes and says that he is a citizen of the United States, and resident of Marino, California; that he verily believes himself to be the original, first and sole inventor or discoverer of the Vibration Translating Means described and claimed in the annexed specifications; that he does not know and does not believe that the same was ever known or used before his invention or discovery thereof, or patented or described in any printed publication in any country before his invention or discovery thereof, or more than two years prior to this application, or in public use or on sale in the United States for more than two years prior to this application; that said invention has not been patented in any country foreign to the United States on

Defendant's Exhibit L—(Continued)

an application filed by him or his legal representatives or assigns more than twelve months prior to this application; and that no application for patent on said invention has been filed by him or his legal representatives or assigns in any country foreign to the United States ~~except as follows:~~

(Sign here first name in full)

CRANFORD P. WALKER

Subscribed and sworn to before me, this 4th day of September, 1937.

MARJORIE McKAY

Notary Publie in and for the said County and State

My Commission Expires July 14, 1941

RECEIVED
SEP 23 ...

164534

Division 5. Paper no. 2

Price of Gazette as published 10d.

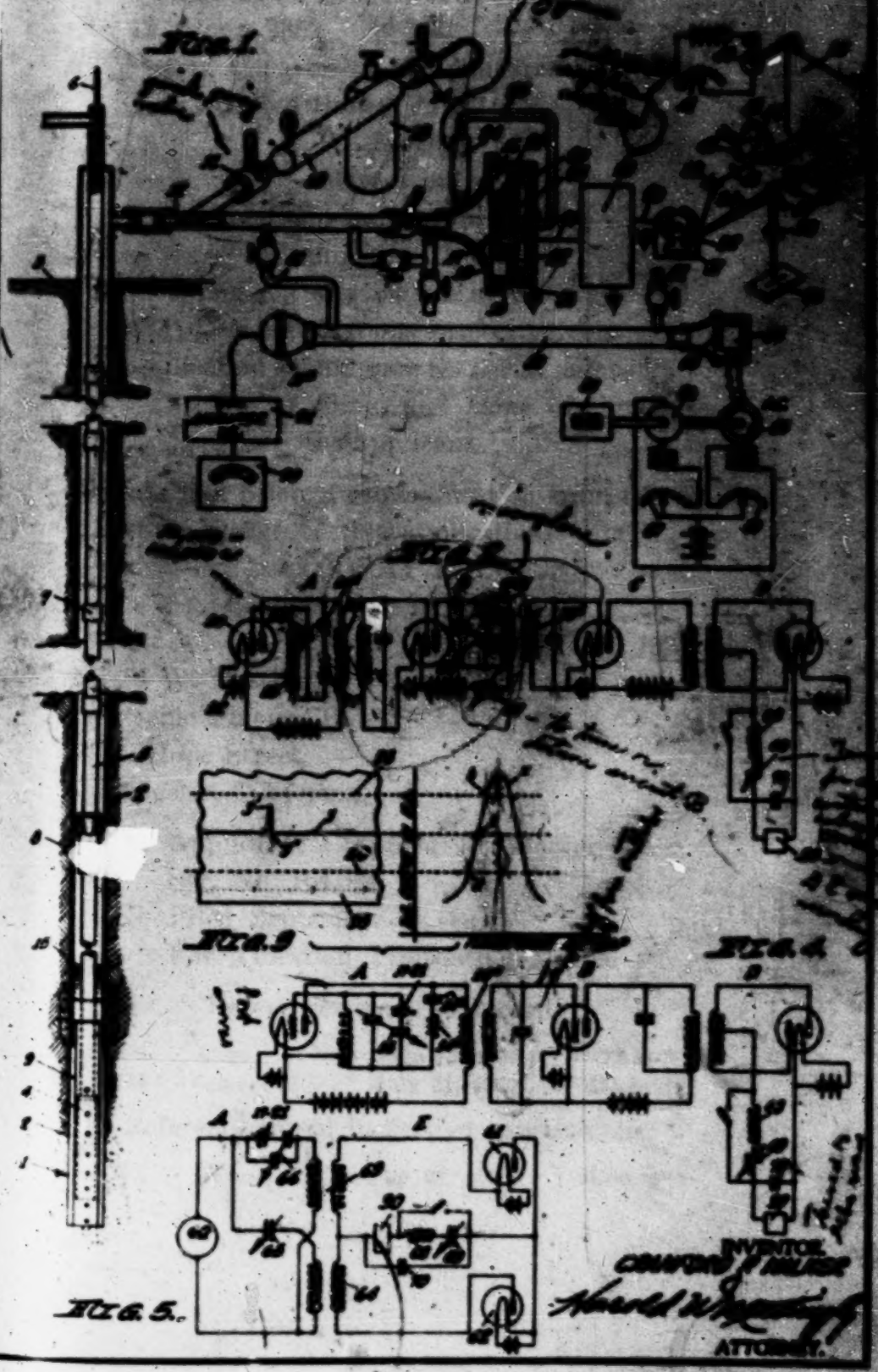


FIG. 1.

FIG. 2.

FIG. 3.

FIG. 4.

FIG. 5.

INVENTOR
CONYERS HILLIER

ATTORNEY.

164534

Defendant's Exhibit L—(Continued)

Div. 42 Room 5882 260 Paper No. 3

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United States Patent Office
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All communications respecting this
application should give the serial number,
date of filing, and name of
the applicant

Please find below a communication from the Examiner in charge of this application.

CONWAY P. COE,
Commissioner of Patents,

January 17, 1938

Harold W. Mattingly,
924 Pacific Finance Bldg.,
621 S. Hope Street,
Los Angeles, California.

Applicant: Cranford P. Walker
Ser. No. 164,534
Filed September 18, 1937
For Vibration Translating Means.

References made of record:

2,043,984	Alder	June 16, 1936	73-51(Vib)
2,047,974	Lehr et al	July 21, 1936	177-352(6)

Reference to aid in further prosecution:

2,008,713	Hayes	July 23, 1935	177-352(7)

Defendant's Exhibit L—(Continued)

Division is required between:

I. Claims 2 through 17, which are specific to the species for recording impulses from a well classifiable in class 177, subclass 352, as evidenced by the patent to Lehr et al, and

II. Claims 18 and 19, drawn to a system for determining pressure wave velocity in a given medium classifiable in class 73 as evidenced by the patent to Alder.

These are clearly independent inventions, classifiable in different divisions of the patent office and requiring independent searches.

Claim 1 may be retained with either group since it is a subcombination of both inventions.

Claim 20 is rejected as non-statutory.

There are more claims in the case than the subject-matter justifies. On response, the number should be materially reduced or the patentable difference between each of the claims pointed out.

H. MARANS

Acting Examiner.

LCL

LCL/LM

Defendant's Exhibit L—(Continued)

1/84

Division 42, Paper No. 4a Jul 16 1938 U. S. Patent Office.

Mail Division Jul 15 U. S. Patent Office.

In the United States Patent Office
Division 42
Room 5882

Cranford P. Walker
Vibration Translating Means
Serial No. 164,534
Filed: Setember 18, 1937

Los Angeles, California
July 11, 1938

Hon. Commissioner of Patents
Washington, D. C.

Sir:

In response to the Examiner's letter of January 17, 1938, please amend as follows:

In the specification, page 4, line 17, after "Serial No." insert—162,699—; same line, after "Filed" insert—September 7, 1937—.

Claim 4, line 3, change "impedances" to read—impedance—.

Claim 9, line 14, change "receifying" to —rectifying—.

Claim 12, line 13, before "rectifying" insert—full wave—.

Cancel claims 18, 19 and 20.

[Long hand notation]: Not entered: which rectifying?

Defendant's Exhibit L—(Continued)

REMARKS

In view of the requirement for division, claims 18 and 19 have been canceled, directing all of the claims in this application to the system for receiving and translating wave patterns from the well, classifiable as indicated by the Examiner in Class 177, Sub Class 352.

The Examiner's criticism that there are more claims in this case than the subject matter justifies is not understood. The applicant has provided a novel system for describing a graphic wave pattern corresponding to the waves or vibrations set up in an oil well for the purpose of making certain described measurements in the well. As a part of such system the applicant has provided a novel electric circuit in which the wave form and wave pattern may be drawn with extreme accuracy and fidelity and in so doing he has produced a new and useful result.

The original claims presented in this application were carefully drawn and each of them is directed to a particular feature of the applicant's device and system different from the remaining claims.

Claim 1 is directed broadly to the applicant's system for producing an observable wave pattern which permits him to study such pattern to determine the various measurements denoted thereby, and this claim specifies the employment of a high frequency circuit, means in the circuit for varying the intensity of the current therein "in accordance

Defendant's Exhibit L—(Continued)

with the wave pattern of the energy wave", and to empley a direct current translating device to "graphically describe a wave pattern corresponding to the pattern of the energy wave". In the absence of a reference patent showing this combination, this claim is clearly patentable.

Claim 2 is directed particularly to the applicant's system in which the microphone is exposed to the gas pressures in the well with a circuit which will translate the movements of the microphone into an observable wave pattern. This claim is clearly distinguishable from claim 1.

Claim 3 is more specific in that it defines the coupling of the microphone in the high frequency circuit has a tuner tending to "tune and detune the circuit * * as it is affected by said echoes". This claim is therefore directed to a particular kind of circuit and a particular relationship between the microphone and the circuit.

Claim 4 specifies that the microphone is adapted to vary its impedance in correspondence with the pressure variations impinging thereon and further specifies an "additional tuning means in said high frequency circuit for varying the sensitivity of said circuit to the tuning effects of said microphone". This later is a distinct limitation, distinguishing this claim from any of the previous claims.

Claim 5 specifically describes the coupling of the microphone in "series with the output circuit of said high frequency circuit". This claim further

Defendant's Exhibit L—(Continued)

specifies "a pair of impedances inversely variable relative to each other" and their relationship in the circuit. This claim is more limited than claim 4 and distinguishes from all of the previous claims.

Claim 6 is similar to claims 4 and 5 in that it is directed to the adjustment of the high frequency circuit but it specifies that the adjustment is such as to produce a direct current output approximately midway between maximum and minimum variations "when said microphone is subjected only to static pressures". This is an important feature of the applicant's device in that the static pressure in various wells differs so widely that an adjustment of this character is frequently necessary in order to produce a satisfactory graph or record of the wave pattern which will be produced as a result of the echoes in the well. It is quite obvious that this claim differs from the preceding claims, since it recites a specific limitation directed to a feature not found in preceding claims.

Claim 7 introduces a new element, namely amplifying means for amplifying the small variations in the current so that they may be used to draw an observable wave pattern.

Claim 8 is clearly distinguishable from the previous claims in that it is specific to the characteristics of the microphone and the tuning condensers in the applicant's circuit.

Claim 9 is similar to claim 2 but specifies that the translating device graphically describes the

Defendant's Exhibit L—(Continued)

wave pattern, whereas claim 2 merely requires an observable wave pattern to be produced.

Claim 10 is similar to claim 6 but recites the tuning of the circuit in terms of the tuning and detuning limits of the microphone to permit the adjustment of the circuit to the particular characteristics of the microphone and to the particular characteristics of the microphone as it is affected by the pressures in a given well.

Claim 11 is similar to claim 10 but introduces the fact that several stages of amplification may be interposed between the high frequency circuit and the translation device.

Claim 12 distinguishes from claim 11 by specifying that the rectifier is a full wave rectifier, enabling the applicant to employ the benefit of both sides of the wave to operate the translation device.

Claim 13 is similar to claim 2 but specifies that the translation device includes (a) a high speed galvanometer, and (b) means actuated by the galvanometer to describe the wave pattern.

Claim 14 is similar to claim 2 but includes the further element of a variable filter interposed between the microphone and the translation device to permit amplification of responses to certain echoes and to minimize the response to others, thus permitting the applicant to readily distinguish between echoes from certain characters of obstructions in the well from echoes from other characters of obstructions. This is particularly important as, for example, in measuring and distinguishing the

Defendant's Exhibit L—(Continued)

number of tubing collars from which the applicant may definitely determine the location of a particular obstruction suspended upon or secured to the tubing string or to measure the wave velocity in a particular well under consideration.

Claim 15 is similar to 14 but is broader in that it does not specify the use of a microphone. It does, however, set up all of the necessary elements to describe an observable wave pattern corresponding to the patterns of the echo waves and the means interposed between the pressure responsive means and the translation device for tuning the system to more readily distinguish said types of echoes from others.

Claim 16 is directed to the feature of tuning the amplifier to the frequency of the high frequency source of current which is an important feature of applicant's system.

Claim 17 is specific to the form of the device shown in Fig. 5 describing the balanced bridge circuit employed therein.

In view of the foregoing explanation as to each of the claims, it is believed that the Examiner will find that each of these claims patentably distinguish from each other, and in the absence of references which show that the limitations of one claim over the others is anticipated or lacks invention, each of these claims must be allowed.

The Examiner must keep in mind in examining this application that the applicant herein is licensed under the Lehr et al patent cited by the Examiner

Defendant's Exhibit L—(Continued)

and in working with the system and method described in that patent has added improvements and refinements in the translation mechanism and system to be employed with the apparatus and in the method disclosed by Lehr et al.

The applicant, by employing the circuit and the circuit elements described in this application, is enabled to draw the patterns with such accuracy and fidelity that the wave patterns may be read in terms not only of fluid level, but of the location of other obstructions in the well and by reason of the ability to distinguish between different portions of the wave pattern, the applicant can translate the wave pattern in terms of tubing collars, tubing catchers, liner tops and other obstructions which may be in the well and can determine which portion of the wave pattern is produced by each of these distinguishable obstructions. His system, therefore, is by no means a simple one, nor is it a minor advance over the art. The applicant is therefore entitled to claims adequately covering his invention unless the Examiner can show that the principles of the invention have been already taught by others in the prior art.

It is therefore believed that the number of claims remaining in this application are by no means excessive and that the applicant is at least entitled to an action on the merits of each of them.

Respectfully submitted,

HAROLD W. MATTINGLY
Attorney for Applicant

HWM mm

Defendant's Exhibit L—(Continued)

260

Div. 42 Room 5882

Department of Commerce
United States Patent Office
Washington
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and not any official by name
Paper No. 5

All communications respecting this application should give the serial number, date of filing, and name of the applicant

Apr 5 1939

Please find below a communication from the Examiner in charge of this application.

CONWAY P. COE
Commissioner of Patents,

Harold W. Mattingly
924 Pacific Finance Bldg.
621 S. Hope St.
Los Angeles, Calif.

Applicant: C. P. Walker
Ser. No. 164,534
Filed Sept. 18, 1937
For Vibration Translating means

Under order 2749, no requirements as to matters of form in the drawing, specification or claims will be made until allowable matter is found in the case or appeal is taken.

Defendant's Exhibit L—(Continued)

References added:

1,428,156	Espenschied	Sept. 5, 1922	178-63 (386.6ux
1,650,934	Chubb	Nov. 29, 1927	250-6 (171M1
1,780,567	Rieber	Nov. 4, 1930	177-351 (352.7ux
2,078,796	Greentree et al	Apr. 27, 1937	177-351 (~~18~~ 17

Pertinent art:

1,550,660	Affel	Aug. 25, 1925	179-171 (M2
Bri. 258,946	Rickets (2 sh. 4 pp.)	Oct. 1, 1926	179-171 (M2

Claims 1 through 17a are rejected as indefinite in "a high frequency" since opinions differ as to what constitutes a high frequency. Note that the patent to Rieber calls a frequency of one thousand, a high frequency. It has not been shown that the particular frequency selected is more than a matter of choice and design. If the applicant can show that there is patentable novelty in the selection of the particular frequency used, the claims should set forth the limits, such as a frequency of 10,000-100,000 cycles.

Claim 1 is further rejected on Rieber and Greentree et al. The latter suggests the use of a rectifier in series with the recorder of the former.

Claim 1 is further rejected on Espenschied and Greentree et al. It would not be invention to connect the output of the amplifier for amplifying impulses from a propeller, to a rectifier and a recorder, in view of the common practice of indicating impulses from vibrations by a recorder connected in that way, as evidenced by the patent to Greentree et al.

Defendant's Exhibit L—(Continued)

Claim 1 is further rejected as incomplete in the absence of means for producing a high frequency current in the high frequency circuit. This claim is also incomplete in the absence of structure for amplifying the modulated wave.

Claims 1, 7, 8 and 9 are further rejected as functional in such matter as "for graphically.....said energy wave". Any dire ct current translating device will not perform this function.

Claim 2, line 7, "current" should be --circuit--.

Claims 2, 3, 4, 5, 6 and 14 are rejected as incomplete since they do not include a connection between the source of high frequency current and the high frequency circuit. As claimed the said source is an idle element. These claims are also incomplete in the absence of amplifying means and in the absence of the rectifier. Claim 6 is also incomplete in the absence of the source of high frequency.

Claims 2 and 15 are rejected on Lehr et al and Rieber. It is not invention to use the same structure between the microphone and recroder of Lehr et al, that is used between the corresponding elements of Rieber.

Claim 2 is further rejected on Lehr et al and Espenschied. It is known that the impulse of Lehr et al is of a very low frequency. It is not invention to use an amplifier which is designed to amplify very low frequencies such as that of Espenschied. Note that Rieber tunes his recorder.

Claims 2, 3, 4, 5 and 6 are further rejected since they do not include an antecedent for "current output".

Defendant's Exhibit L—(Continued)

Claims 2 through 13 and 17a are rejected as old combinations on Lehr et al. There is no different combination between I—the well, II—the microphone and the amplifying means and III—the recorder, of the claims than there is between the equivalent elements of the reference. Any novelty is in II and not in the combination. Element II is of general application so its details cannot lend patentability to the combination. Element II should be claimed by itself as evidence by the patent to Espenschied.

Claims 7 through 13 are further rejected as incomplete in the absence of the source of high frequency and its connection to the high frequency circuit. Claims 8, 9, 10 and 13 are also incomplete in the absence of the amplifying means. Claims 10, 11, and 12 are also incomplete in the absence of the recorder. Claim 13 is also incomplete since it does not bring out any relation between the matter before the comma of line 9 and the matter after that comma. Claim 8 does not include an antecedent for "the output circuit".

Claims 14 and 16 are rejected as aggregational. There is no patentable relation between I—the specific modulating means and II—the filter. Each of these operates in the same way in the absence of the other as evidenced by the patents to Chubb and Rieber. Note that Rieber tunes his recording means for the purpose of amplifying certain of the echos from certain obstructions.

Defendant's Exhibit L—(Continued)

Claim 15 is further rejected as incomplete in the absence of the amplifying means and recorder.

Claim 15 is further rejected on Lehr et al alone. This claim differs from the reference only in the inclusion of a filter. But it is not invention broadly to use a filter wherever a filter is desirable.

Claim 16 is further rejected as incomplete in the absence of the relation between the tuning of the amplifier and the different frequencies produced by the source. For instance, if the amplifier were untuned the system would not operate.

H. O. CUTTING
Examiner

LCL
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Division 42, Paper No. 6 Oct 3 - 1939 U. S. Patent Office.

Mail Division Oct 2 1939 U. S. Patent Office.

In the United States Patent Office
Division 42 — Room 5882

Cranford P. Walker
Vibration Translating Means
Serial No. 164,534
Filed September 18, 1937

Los Angeles, California
September 29, 1939

Hon. Commissioner of Patents
Washington, D. C.

Sir:

In response to the Office action of April 5, 1939,

Defendant's Exhibit L—(Continued)

please amend the above identified application as follows:

Claim 17, cancel from "a" in Line 6 through "current," in Line 7; Line 13, after the comma, insert

B[1]

—means for supplying a current at a frequency many times greater than the frequency of the pressure echoes desired to be translated,—; same line, cancel "high frequency".

Cancel Claims 1 through 16, inclusive, and substitute the following claims:

B[2]

—21. In a system for receiving and translating pressure echoes from a well, a microphone adapted to translate pressure variations impinging thereon to corresponding electrical variations, means coupling said microphone to said well to expose said microphone to gas pressures in the well, a circuit capable of being tuned relative to a selected frequency many times greater than the frequency of the echoes desired to be translated, means supplying said circuit with current at said selected fre-

said circuit including

quency, ∧ ~~means coupling~~ said microphone ~~to said~~

so disposed therein as

~~circuit~~ ∧ to impose the electrical variations produced by said microphone upon the curernt in said circuit, and ~~translating~~ means coupled to said circuit and responsive to variations of current in said circuit

reproduction of

for describing an observable wave pattern ∧ ~~corresponding to~~ the pressure variations in said well.

Defendant's Exhibit L—(Continued)

—22. In a system for receiving and translating pressure echoes from a well, a microphone adapted to translate pressure variations impinging thereon to corresponding electrical variations, means coupling said microphone to said well to expose said microphone to the gas pressure in the well, a circuit capable of being tuned relative to a selected frequency many times greater than the frequency of the echoes desired to be translated, means supplying said circuit with a current at said selected frequency, ~~means coupling~~ said circuit including said microphone ~~in said circuit~~ so disposed therein as to act as a tuning means tending to tune and de-tune said circuit relative to said supplied frequency as the circuit is affected ~~it is effected~~ by the electrical variations produced by said echoes, to thereby accordingly vary the current of said circuit, and ~~translating~~ means coupled to said circuit for receiving varying current from said circuit and for describing an observable wave pattern reproduction of ~~corresponding to~~ the pressure variations impinging on said microphone.

~~23. In a system for receiving and translating~~ pressure echoes from a well, a microphone adapted to translate pressure variations impinging thereon to corresponding impedance ~~electrical~~ variations, means coupling said microphone to said well to expose said ~~microphone to the gas pressure in the well, a circuit~~

Defendant's Exhibit L—(Continued)

capable of being tuned relative to a selected frequency many times greater than the frequency of the echoes desired to be translated, means supplying said circuit with a current at said selected frequency, ∧ ~~means coupling~~ said microphone ~~in said~~ so disposed therein as ~~circuit~~ ∧ to act as a tuning means tending to tune said circuit including and de-tune said circuit relative to said supplied frequency as it is effected by the electrical variations produced by said echoes, to thereby accordingly vary the current of said circuit, a pair of tuning impedances in said circuit inversely variable relative to each other, one in series with said microphone and the other shunted across both said microphone and said first impedance for varying the tuning effect of the microphone upon said circuit, and ~~translating~~ means coupled to said circuit for receiving varying current from said circuit and for reproduction of describing an observable wave pattern ∧ ~~corresponding to~~ the pressure variations impinging on said microphone.

—24. In a system for receiving and translating pressure echoes from a well, a microphone adapted to translate pressure variations impinging thereon to corresponding electrical variations, means coupling said microphone to said well to expose said microphone to the gas pressure in the well, a circuit capable of being tuned relative to a selected frequency many times greater than the frequency of the echoes desired to be translated, means supply-

Defendant's Exhibit L—(Continued)

ing said circuit with a current at said selected frequency, ~~means coupling~~ ∧ said microphone ∧ ~~in said circuit~~ to act as a tuning means tending to tune and de-tune said circuit relative to said supplied frequency as it is effected by the electrical variations produced by said echoes, to thereby accordingly vary the current of said circuit, rectifying means coupled to said circuit to produce a direct current the amplitude of which varies in accordance with the varying current in said circuit, ~~a direct current~~ and responsive to variations in amplitude of said direct current ~~translation device~~ means ∧ coupled to said rectifier ∧ for describing a pattern of the waves impinging on said microphone, and means in said circuit for adjusting the natural period of oscillation of said circuit to produce a direct current from said rectifier approximately midway between maximum and minimum values when said microphone is subjected only to static pressures.

—25. In a system for receiving and translating pressure echoes from a well, a microphone adapted to translate pressure variations impinging thereon to corresponding electrical variations, means coupling said microphone to said well to expose said microphone to the gas pressure in the well, a circuit capable of being tuned relative to a selected frequency many times greater than the frequency of the echoes desired to be translated, means supply-

Defendant's Exhibit L—(Continued)

~~ing said circuit with a current at said selected fre-~~
~~said~~ circuit including
quency, ∧ ~~means coupling~~ said microphone ~~in said~~ so disposed therein as
~~circuit~~ ∧ to act as a tuning means tending to tune and de-tune said circuit relative to said supplied frequency as it is effected by the electrical variations produced by said echoes, to thereby accordingly vary the current of said circuit, translating means coupled to said circuit for receiving varying current from said circuit and for describing an reproduction of
observable wave pattern ∧ ~~corresponding to~~ the pressure variations impinging on said microphone, and means interposed between said microphone and said translating means for tuning said sytem to respond more readily to echoes from selected obstructions than to pressure variations emanating from other ~~sources.~~

(Add C1)

REMARKS

Upon a review of the claims of this application in view of the Examiner's criticism of the claims as being incomplete, claims 1 through 16 have been completely redrafted as Claims 21 through 25, particular care being taken in the redrafting of these claims to insure completeness and definiteness of each element recited in the claim.

The Examiner will note that all of the claims remaining in this application are specifically directed to the applicant's system for receiving and

Defendant's Exhibit L—(Continued)

translating pressure echoes from a well so as to describe a line or wave pattern to permit its observation and study and to insure that the observable line or wave pattern will correspond precisely to the pattern of the pressure echoes impinging upon the microphone.

Moreover, one of the important things which is accomplished by the applicant's system is that of accenting certain of the echoes received from the well so as to permit the ready distinguishing of these echoes from other echoes emanating from other sources as well as to permit each individual one of these accented echoes to be distinguished from the others emanating from a similar obstruction in the well.

The applicant is licensed under the Lehr et al patent cited by the Examiner but when applicant attempted to use the mere microphone amplifier recorder construction as shown and described in this patent, he found that in many instances the graphic recording which was received required an expert study thereof by persons having considerable experience in the reading of such records in order to permit such person to distinguish and recognize the recordings of the echoes from different obstructions in the well. For example, tubing catchers, one or more of which may be located upon the string of flow tubing above the surface of the fluid, would produce echoes which would graphically record upon the chart in much the same manner as the echo back from the fluid surface. Echoes from the collars

Defendant's Exhibit L—(Continued)

which interconnect the adjacent sections of the tubing string would produce waves on the record chart but which would be so intermingled with reverberations and echoes produced by other obstructions in the well such as the space between adjacent sections of the casing at the joints thereof or tubercules which might be upon the interior surface of the casing or perforations in the casing, so that it was exeremely difficult to distinguish the recordings of echoes from the tubing collars and other disturbance vibrations.

One of the important things discovered by this applicant was that instead of attempting to mathematically calculate the velocity of the pressure waves through the gaseous medium in the well and to thereby compensate for the total time period elapsing between the production of the pressure impulse and the arrival at the ground surface in different wells under measurement (and the velocity of sound or pressure waves in oil wells varies over wide limits between different wells though they may be located in the same field and may be expected to have the same character of gas, the same density of gas and the same temperature of gas) he could directly measure same.

The applicant conceived the idea that if he could produce a translating system which could receive the pressure variations in the well resulting from the echoes from the various obstructions in the well and draw an accurate picture of these pressure vari-

Defendant's Exhibit L—(Continued)

ations, he would find that the picture or record of an echo from one kind of obstruction would be different from the record of an echo from a different kind of obstruction and that he could therefore in any chart distinguish the echoes from different obstructions from each other. Particularly he desired to record the echoes from successive tubing collars so as to simplify a fluid level determination by merely counting up the tubing collar echoes and multiplying them by the known length of each section of pipe with which the tubing string is constructed.

An additional discovery was made by the inventor, namely, that with a receiving and translation system which would be entirely accurate for one well would not be entirely accurate nor draw a favorable reproduction of the pressure echoes when applied to another well but that something was necessary to permit a ready adjustment of the translation system to different wells in order to achieve this purpose. For example, in one well it was necessary to de-sensitize the microphone or the effect of the microphone upon the translation system while in other wells it was impossible to get good readable results unless the microphone was rendered extremely sensitive or the system was rendered extremely sensitive to the effects produced by the microphone.

He therefore devised, not merely a system of beating or modulating or adding one current to another, as did Rieber and Espenschied and Greentree, but

Defendant's Exhibit L—(Continued)

he produced a system peculiarly adapted to the problem he was attempting to solve, namely, how to draw an observable wave pattern which would be an accurate and favorable reproduction of the wave patterns in the well.

It is therefore contended that the applicant has made an advance in the art of receiving and translating pressure echoes from a well which is not the mere production of a new element in an old combination but is instead a new and patentable combination.

Lehr et al disclose a system for producing an impulse in a well and for receiving and recording pressure echoes emanating from the well. The applicant is not claiming this combination in this case but instead he is claiming a combination of electrical elements which permits a microphone and a registering or recording device to be employed to accurately reproduce the varying pressure conditions existing in the well.

This combination comprises at least three essential elements: (1) a microphone; (2) a circuit and the manner in which that microphone is connected in that circuit to produce electrical variations corresponding to the variations of pressure in the well; and (3) a translation or recording device which can receive the varying electrical values in the circuit and describe the observable wave pattern. The applicant utilizes these three elements in a manner and mode of operation which is distinct from the

Defendant's Exhibit L—(Continued)

manner and mode of operation employed in the microphone and recorder of Lehr et al. At this point it should be noted that Lehr's amplifier is not an element in the Lehr system which corresponds to the applicant's circuit and source of high frequency for the reason that applicant's circuit and source of high frequency are not used merely to amplify the movements of the microphone but are employed to translate the movements of the microphone with a fidelity impossible to be achieved by any amplification.

It is believed therefore that the Examiner's rejection of claims in this application on the ground of old combination is not well taken since such rejection must be based upon a finding in the prior art of the same or equivalent elements cooperating in the same manner or mode of operation to produce the same result. Neither the result nor the mode of operation nor the elements disclosed by the applicant are found in Lehr et al.

New Claim 21, which represents old Claim 2 rewritten to avoid formal objections, now defines the applicant's system in terms which clearly distinguish it from Lehr et al or from any combination of Lehr plus Rieber. This claim defines the use of the microphone exposed to the well to respond to pressure variations in the well, a circuit into which said microphone is coupled and to which circuit a source of current in a known frequency many times greater than that of the echoes desired to be trans-

Defendant's Exhibit L—(Continued)

lated so as to produce for the translation device an accurate reproduction of the pressure waves impinging on the microphone.

Lehr et al do not show this general combination and the substitution of the Rieber system for the Lehr amplifier would not satisfy the terms of this claim, even though such substitution could be made without invention, for the reason that this claim specifies supplying to the circuit a current of a frequency many times greater than the frequency of the echoes desired to be translated. Rieber, on the other hand, produces from his measuring instrument a high frequency and then combines this with a low frequency added to his circuit. The applicant here was faced with a problem of reproducing low frequency acoustical vibrations and none of the teaching of the Rieber patent would assist him in determining how to achieve the result he obtains.

Moreover, the teaching of the Rieber patent is by no means so obvious as to suggest its use or to suggest how it could be used in the Lehr system to produce the results obtained by the applicant. It is only after the Examiner has seen the disclosure of the applicant's system that he is able in his imagination to try to supply the deficiencies of Lehr as a reference against the applicant by seeking in some other patent a circuit which he considers bears some resemblance to the applicant's circuit.

It is believed that upon reconsideration the rejection based upon the combination of Lehr et al and Rieber will be withdrawn.

Defendant's Exhibit L—(Continued)

New Claim 22 is substituted for old Claim 3 and defines the applicant's circuit which is capable of being tuned to a selected frequency and supplied with that selected frequency and which has the microphone so connected therein as to tune and detune the circuit to that selected frequency depending upon variations of pressure impulses impinging upon the microphone.

It is noted that in the previous Office action the subject matter of this claim was rejected only on the ground that it was directed to old combination. In view of the foregoing remarks with regard to old combination, and in addition to the fact that this claim defines a peculiar relation between the microphone and its effect upon the circuit, it is believed that the Examiner will find the subject matter of this claim allowable.

New Claim 23 represents old Claim 4 rewritten, this claim defining the same subject matter as Claim 22, but with the addition of an additional tuning means in the circuit which allows the sensitivity of this circuit to the tuning effects of the microphone to be adjusted and varied so as to readily allow the translation system to be adapted to the acoustical conditions existing in a particular well under measurement. This is subject matter not found in any of the references and introduces an element which further distinguishes this claim as a new combination from any combination shown in Lehr et al.

New Claim 24 represents old Claim 5 rewritten. This claim is similar to Claim 23 but specifies the

Defendant's Exhibit L—(Continued)

tuning means in the circuit as constituting a pair of tuning impedances inversely variable relative to each other and specifies the manner of their connection in the circuit with reference to each other and to the microphone. This claim is clearly allowable.

New Claim 25 is old Claim 15 rewritten to present this subject matter in better form and includes the subject matter of Claim 22 with the additional element of variably tuning the system to render it peculiarly responsive to selected echoes. This defines the structure by which the applicant secures the important result of being able to so accent the tubing collar echoes as to make the record of each one of them stand out individually so that they can be distinguished one from the other as well as distinguished from echoes from other obstructions. This is more than any mere inclusion of a filter which would tend to filter out some objectionable vibrations but instead provides necessary mechanism for increasing the sensitivity of the circuit to these peculiar vibrations and to produce a more clearly readable record therefrom.

It is believed that upon reconsideration this claim will likewise be found allowable over any of the references of record.

Reconsideration of Claim 17 as amended is requested, this claim now avoiding the formal deficiencies of this claim. This claim is directed to a particular balanced bridge circuit which may be

Defendant's Exhibit L—(Continued)

employed as one species of system and which is not suggested by any of the references or any combination of them.

In making the foregoing amendment, a sincere attempt has been made to meet each and every of the rejections and objections made by the Examiner particularly to point out why the applicant's system as presented in these claims is not a mere recital of an old combination but is in fact the recital of a new combination of elements to produce a new result.

It is believed that upon reconsideration each and every of the claims now presented will be found allowable and an early favorable action is respectfully requested.

Respectfully submitted,

HAROLD W. MATTINGLY

Attorney for Applicant

HWM:MM

Defendant's Exhibit L—(Continued)

260

Div. 42 Room 5882

Department of Commerce
United States Patent Office
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Paper No. 7

All communications respecting this application should give the serial number, date of filing, and name of the applicant

Apr 22 1940

Please find below a communication from the Examiner in charge of this application.

CONWAY P. COE
Commissioner of Patents,

Harold W. Mattingly
924 Pacific Finance Bldg.
621 S. Hope St.
Los Angeles, California

Applicant: Cranford P. Walker
Ser. No. 164,534
Filed Sept. 18, 1937
For Vibration Translating Means

Responsive to the amendment filed October 2, 1939.

In line 15 of page 11, "D" should be C.

Defendant's Exhibit L—(Continued)

The description of Fig. 5 is believed to be inaccurate in the last three lines of page 13. Assuming that the inpedances of the coils 63 and 64 are equal, then the two branches can not be balanced if the impedence of the microphone 17-21 and that of impedance 65 are made equal. A balanced condition requires that both branches be tuned to the same frequency; accordingly, impedance 65 should be made equal to the combined impedance of the microphone 17-21 and the condensers 66.

Furthermore, applicant has not stated how the branches are tuned with respect to generator 60. Are these circuits, like the input of amplifier B in Fig. 3, tuned to the (normal) frequency of the oscillator or are they, like the output of the amplifier B in Fig. 2, detuned with respect to the oscillator?

Claim 17 is specific to Fig. 5. New claims 21 through 25 are indefinite, but so far as they are clear they are believed to be specific to Fig. 2. Unless applicant can show that one or more of the claims is generic, or that all of the claims are readable on Fig. 5, division will be necessary between claim 17 and the remaining claims. In the event applicant considers claims 21-25 to cover the species disclosed in Fig. 5 he is requested to read claims 21-25 on that figure.

In Fig. 4 the circuit of amplifier B is tuned to the normal frequency of the oscillator, and variation of the microphone does not vary its tuning but merely changes the efficiency of energy transfer to it. Accordingly claims 21 through 25, calling for a circuit

Defendant's Exhibit L—(Continued)

coupled to the generator which is capable of being tuned, are not readable on Fig. 3.

In Fig. 5 circuit E is not tunable as claimed, and the examiner is not able to read the claims clearly on Fig. 5.

Presumably, therefore, the tunable output circuit of amplifier B in Fig. 2 is the "circuit" of line 6, and claims 21-25 are intended to read on Fig. 2.

Claim 2 is rejected as being inaccurate since the microphone is not connected to the tunable output of amplifier B but is connected in it, forming part of it. That is, the capacity of the microphone plays a part in the tuning of the "circuit" of line 6 even when the microphone is not receiving a pressure wave.

Claim 21 would be in better form if it were revised to make clear that "the means coupling the microphone to the said circuit to impose electrical variations....." is not a separate and distinct element, but is in fact a part of the "circuit" of line 6. This same objection applies also to claims 22, 23, 24 and 25.

Claims 21 through 25 are rejected as being functional in the last four lines. "Translating means" do not necessarily perform the function set out in the last four lines. The objection can be avoided by canceling "translating", so that the functional statement will define the "means" instead of serving merely to recite an additional function for it beyond its "translating" function.

Defendant's Exhibit L—(Continued)

Claims 21 through 25 are rejected as being indefinite in the use of the words "corresponding to" (e.g. line 15 of claim 21) and to this extent failing to define the invention with the particularity required by the statutes. The translating means must describe a wave pattern which reproduces the variations present in the pressure wave. It is not enough that the recorded wave pattern shall "correspond" to the pressure waves—in the Lehr system, the recorded wave pattern "corresponds" (e.g., in time of arrival, frequency of occurrence, maximum amplitude, etc.) to the pressure wave in the well.

This case is believed to contain patentable subject-matter. The above explanations are made to indicate the features which, in the examiner's opinion, must be incorporated into the claims in order properly to define that subject matter.

H. O. CUTTING
Examiner

J.D.S.
JDS/ec

Defendant's Exhibit L—(Continued)

Division 42, Paper No. 8 Oct 21 1940 U. S. Patent Office.

In the United States Patent Office
Division 42 — Room 5882
Via Air Mail
Confirmation
Regular Mail

Mail Division Oct 19 1940 U. S. Patent Office.

Cranford P. Walker
Vibration Translating Means
Serial No. 164,534
Filed September 18, 1937

Los Angeles, California
October 17, 1940

Hon. Commissioner of Patents
Washington, D. C.

Sir:

In response to the Office action of April 22, 1940, please amend the above identified application as follows:-

Page 11, Line 15, change "D" to read —C—; Line 30, before "line" insert —straight—.

Page 12, Line 17, before "curve" insert —straight lineportion of the—; Line 18, change "lighting" to read —lying—.

Page 13, Line 28, before "imped-" insert —combined effect of the—; Line 29, after "and" insert —its associated variable impedances 66 is equal to—; Line 30, cancel "are equal".

Page 14, Line 5, change "effect" to read

Defendant's Exhibit L—(Continued)

—affect—; Line 7, change "thereof" to read —of the microphone 17-21—.

Claim 21, Line 10, cancel "means coupling" and substitute —said circuit including—; same line, cancel "to said circuit" and substitute —so disposed therein as—; Lines 12 and 13, cancel "translating"; Line 15, change "corresponding to" to read —reproduction of—.

Claim 22, Line 10, cancel "means coupling" and substitute —said circuit including—; same line, cancel "in said circuit" and substitute —so disposed therein as—; Line 12, cancel "it is effected" and substitute —the circuit is affected—; Line 15, cancel "translating"; Line 17, cancel "corresponding to" and substitute —reproduction of—.

Claim 23, Line 4, change "electrical" to read —impedance—; Line 10, cancel "means coupling" and substitute —said circuit including—; cancel from "in" in Line 10 through "circuit" in Line 11 and substitute —so disposed therein as—; Line 20, cancel "translating"; Line 22, change "corresponding to" to read —reproduction of—.

Claim 24, Line 10, cancel "means coupling" and substitute —said circuit including—; same line cancel "in said circuit" and substitute —so disposed therein as—; Line 18, cancel "a direct current translation device" and substitute —means—; Line 19, after "rectifier" insert —and responsive to variations in amplitude of said direct current—.

Claim 25, Line 10, cancel "means coupling" and substitute —said circuit including—; cancel from

Defendant's Exhibit L—(Continued)

"in" in Line 10 through "circuit" in Line 11 and substitute —so disposed therein as—; Line 17, change "corresponding to" to read —reproduction of—.

Add the following claims:

C1

—26. In a system for receiving and translating pressure echoes from a well, a microphone adapted to translate pressure variations impinging thereon to corresponding impedance variations, means coupling said microphone to said well to expose said microphone to gas pressure in the well, a circuit including a source of alternating current of a frequency many times greater than the frequency of the echoes desired to be translated, said circuit including said microphone so disposed therein as to vary the alternating current therein in accordance with pressure variations impinging on said microphone, and means coupled to said circuit and responsive to variations of said alternating current in said circuit for describing an observable wave pattern reproduction of the pressure variations in said well.

—27. In a system for receiving and translating pressure echoes from a well, a microphone adapted to translate pressure variations impinging thereon to corresponding impedance variations, means coupling said microphone to said well to expose said microphone to gas pressure in the well, a circuit including a source of alternating current of a fre-

Defendant's Exhibit L—(Continued)

quency many times greater than the frequency of the echoes desired to be translated, said circuit including said microphone so disposed therein as to vary the impedance of said circuit and to thereby vary said alternating current in accordance with the pressure variations impinging on said microphone, and means coupled to said circuit and responsive to said alternating current in said circuit for describing an observable wave pattern reproduction of the pressure variations in said well.

—28. In a system for receiving and translating pressure echoes from a well, a microphone adapted to translate pressure variations impinging thereon to corresponding impedance variations, means coupling said microphone to said well to expose said microphone to gas pressure in the well, a circuit including a source of alternating current of a frequency many times greater than the frequency of the echoes desired to be translated, said circuit including said microphone so disposed therein as to vary the impedance of said circuit and to thereby vary said alternating current in accordance with the pressure variations impinging on said microphone, a pair of impedances in said circuit inversely variable relative to each other, one in series with said microphone and the other shunted across both said microphone and said first impedance for varying the effect of the microphone on said circuit, and means coupled to said circuit and responsive to variations of said alternating current in said circuit for describing an observ-

Defendant's Exhibit L—(Continued)

able wave pattern reproduction of the pressure variations in said well.

—29. In a system for receiving and translating pressure echoes from a well, a microphone adapted to translate pressure variations impinging thereon to corresponding impedance variations, means coupling said microphone to said well to expose said microphone to gas pressure in the well, a circuit including a source of alternating current of a frequency many times greater than the frequency of the echoes desired to be translated, said circuit including said microphone so disposed therein as to vary the impedance of said circuit and to thereby vary said ~~said~~ alternating current in accordance with the pressure variations impinging on said microphone, means coupled to said circuit and responsive to variations of said alternating current in said circuit for describing an observable wave pattern reproduction of the pressure variations in said well, electrical echo accenting and ∧ means interposed between said microphone causing and said last named means for ~~tuning~~ ∧ said system periodically recurring to respond more readily to ∧ echoes from ~~selected obstructions~~ (∧D^6) than to pressure variations emanating from other sources.

30. In a system for receiving and translating pressure echoes from a well, a microphone adapted to translate pressure variations impinging thereon to corresponding impedance variations, means

Defendant's Exhibit L—(Continued)

coupling said microphone to said well to expose said microphone to gas pressure in the well, a tunable circuit including a source of alternating current of a frequency many times greater than the frequency of the echoes desired to be translated, another tunable circuit coupled thereto, said microphone being so disposed in one of said circuits to act as a tuning means therefor tending to tune and detune said circuits relative to each other as the circuit including the microphone is affected by the microphone variations produced by said echoes, to thereby accordingly vary the alternating current in said circuits, and means coupled to said circuits and responsive to variations of said alternating current in said circuits for describing an observable wave pattern reproduction of the pressure variations in said well.—

REMARKS

The Examiners' suggestions in connection with the specification and claims of this application are sincerely appreciated and have been incorporated into the specification and claims as now amended.

The description of Fig. 5 in the last three lines of Page 13 has been corrected so as to recite the fact that the combined impedances of the microphone and variable impedances 66 is equal to the impedance 65.

However, the question raised by the Examiner as to whether or not the two branch circuits in Fig. 5 are tuned with respect to the generator 60 is be-

Defendant's Exhibit L—(Continued)

lieved to be best answered by the statement that they do not have to be balanced in order to be operative though it is true that if they are so tuned small variations in pressure will produce a relatively greater affect in the circuit and under some conditions this sensitivity might be desirable. However, such high ratio of response may not be particularly desirable especially when the system is used upon wells in which reverberations and disturbance echoes are to be separated from desired tubing collar echoes from actual obstructions in the well, under which conditions it is desirable that only the larger pressure variations are desired to be effective upon a system.

In Claims 21 through 25 the microphone is positively recited as being located in the circuit, thus avoiding the inference that there is a separate element required to couple the microphone to the circuit. Also each of these claims has been amended by cancelling the objectionable expression "translating" in accordance with the Examiner's suggestion.

Claims 21, 22, 23 and 25 have been amended to describe the observable wave pattern as a "reproduction of" the pressure variations impinging on the microphone or the pressure variations existing in the well, thus avoiding the criticism noted by the Examiner on the grounds of functionality and indefiniteness. This latter criticism, however, did not apply to Claim 24.

Defendant's Exhibit L—(Continued)

The Examiner's criticism of Claim 2 is not understood since in the amendment of October 2, 1939 instructions were given to cancel Claims 1 through 16 and if Claim 2 has not been cancelled, this will be the authority of the Examiner to cancel this claim.

With regard to the Examiner's discussion of the species defined in Claims 21 through 25 and in Claim 17, it was believed that Claims 21 through 25 as originally presented were readable upon all of the three forms of the invention shown and described in this application. However, upon reviewing these claims, it appears that the Examiner is correct and these claims will read only upon the form of the invention illustrated in Fig. 2.

For this reason new Claims 26 through 30 are presented herewith, Claims 26, 27, 28 and 29 having been carefully drawn to include within their terms expressions which are generic to all of the three species of invention.

Claim 26 defines the employment of the source of high frequency in connection with the circuit which includes the microphone so arranged that the microphone will "vary the alternating current" in the circuit in accordance with pressure variations impinging upon the microphone. This expression will read equally as well upon Fig. 2 as upon Fig. 4 and Fig. 5, in each of which claims of the invention the affect of pressure waves on the microphone is to vary the alternating current in the circuit in accordance with the pressure variations.

Defendant's Exhibit L—(Continued)

In Fig. 2 the affect of the microphone is to vary the amplitude of the alternating current frequency; in Fig. 4 the affect of the microphone is to vary the frequency of the alternating current source and thus produce in the portion B of the circuit an alternating current whose amplitude is in correspondence with the pressures impinging upon the microphone; in Fig. 5 the affect of the microphone is to vary the alternating current in the portion A of the circuit in accordance with the pressure variations and thus produce in the portion E of the circuit a "varying alternating current" which ultimately results in the bridge circuit in producing a direct current, the amplitude of which corresponds to the pressure on the microphone.

New Claim 30 is presented as being generic to the forms of the applicant's system shown in Fig. 2 and Fig. 4, this claim rectifying the fact that there are two circuits, both tunable, and the microphone as being located in one of the circuits so as to tune and detune that circuit relative to the other to accomplish the result set forth.

Each of the new Claims 26 through 30 is clearly allowable over any of the references of record and being generic the applicant is entitled in this application to separate species claims such as Claims 21 through 25 specific to Fig. 2, and Claim 17 specific to Fig. 5, and Claim 30 which is specific only to Figs. 2 and 4.

Defendant's Exhibit L—(Continued)

It is believed therefore that each of the claims now presented is properly allowable in this application and an early favorable action is respectfully requested.

Respectfully submitted,
HAROLD W. MATTINGLY
Attorney for Applicant

HWM:MM

1/84

Mail Division Dec 23 1940 U. S. Patent Office.
Division 42, Paper No. 8 Dec. 26 1940 U. S. Patent Office

In the United States Patent Office
Division 42 Room 5882

Cranford P. Walker
Vibration Translating Means
Filed September 18, 1937
Serial No. 164,534

SUPPLEMENTAL AMENDMENT

Los Angeles, California
December 18, 1940

Commissioner of Patents
Washington, D. C.

Sir:

Supplementing the amendment of October 17, 1940, please amend the above identified application as follows:

Page 1, Line 15, before "reflected" insert—par-

Defendant's Exhibit L—(Continued)

tially—; same line, before "them" insert—each of —; Line 22, after "distinct" insert—pressure-time—.

Page 2, Line 17, change the comma to read—or —; Line 18, cancel "or other vibrations"; same line, before "wave" insert—pressure-time—; Line 20, change "vibrations" to read—pressure wave or echoes—.

Page 3, Line 7, before "impedance" insert—electrical—; Lines 14 and 25, change "vibrations" to read—pressure variations—; Line 25, before "wave" insert—pressure-time—.

Page 4, Line 18, before the period, insert—which has now issued as United States Letters Patent No. 2,156,519—

Page 5, Line 2, change "2" to read—4—; Line 27, cancel "quick opening".

Page 6, Line 5, before "reflected" insert—partially—; cancel from "including" in Line 6 through the period in Line 9 and substitute

D1

—such as the tubing collars 7, the tubing catcher 8, the top of the liner 9 or any other obstruction which may be in the well and exposed above the fluid surface as well as partially reflected back by the surface 15 of the fluid within the well.—

Page 7, Line 2, change "constitutes" to read—is constituted by—.

Page 8, Line 15, before "wave" insert—pressure-time—; Lines 15 and 16, cancel "transmitted by the diaphragm".

Defendant's Exhibit L—(Continued)

Page 10, Line 11, change "31" to read—30—.

Page 11, Lines 8 and 9, change "reactance" in both instances to read—capacitance—; Line 10, after "other" insert a period; cancel from "the" (second occurrence) in Line 10 through the period in Line 13 and substitute the following:

D2

—The condensers 56 are so arranged that the net capacitance of the network made up of condensers 56 and microphone 17-21 remains unchanged with adjustment of condensers 56. Since a decrease of the capacitance of the series part and an increase of the capacitance of the shunt part of condenser group 56 reduces the effect of microphone capacitance variation upon the net capacitance variation of the network, it is possible to adjust for pressure variation levels occurring under various circumstances. This allows operation of the associated carrier amplifier and recording equipment at an optimum level. The condensers 56 when so arranged do not affect the static tuning of the circuits with which they are associated—;

Cancel from "A" in Line 17 through the period in Line 21 and substitute

D3

—The direct current input to the recorder 30 is preferably adjusted to approximately one-half of its full scale value when no echoes are being received by the microphone as by adjusting the frequency of the oscillator circuit A or by adjusting the tuning of the amplifier circuit B so that the

Defendant's Exhibit L—(Continued)

normal steady direct current supplied to the recorder 30 will centralize the light beam 34 on the chart 35.—; Line 22, before "circuit" insert—output—, and after "circuit" insert—of—.

Page 12, Line 4, change "positive" to read—negative—; Line 5, change "close" to read—open—; Line 11, change "negative" to read—positive—; Line 13, change "fluctuation" to read—deflection—.

Page 13, Line 2, change "tuned" to read—resonant—; Line 12, cancel "is" and substitute—may be —; same line, after the comma insert—is—.

Page 14, Line 12, after the period insert

D4

—In the usual form of this system, the circuits are preferably not tuned with respect to the high frequency carrier source. Sufficient sensitivity is available when the circuit is operated close to balance. Proper impedance matching of the bridge to the oscillator and recording circuit and utilization of the power capabilities of the circuit permit operation without amplification. Tuning of the coupling transformers 63 and 64 with their associated condenser circuits to the generator 60 frequency so that the variations of the microphone capacitance cause both bridge unbalance and microphone circuit tuning or detuning results in higher sensitivity but circuit adjustments when using such tuned arrangement are more difficult.

D5

Line 24, change "amplifying" to read—accenting

Defendant's Exhibit L—(Continued)

—; Line 25, before "echoes" insert—periodically recurring—; Line 28, cancel from "Also" to the end of the page and insert the following paragraphs:

D5

—Under some conditions encountered in wells a series of reflections from periodically occurring obstructions become obscure on the part of the record corresponding to the lower portion of the well due to excessive attenuation, oscillations in the instrument piping, reverberations in the well or to undesired echoes from pipe joints. The depth in the well to which these periodically occurring reflections can be recorded can be greatly increased through tuning of the recording circuit to a frequency corresponding to the number of collar or pipe joint echoes received per second. Narrowing of the frequency band recorded by the galvanometer in tuning, although depreciating the record detail, readily permits locating the well fluid level with respect to collars down to the fluid. The sharpness of tuning determines the attenuation characteristic so that the wave shape of the received reflections need not be smoothed any more than necessary in order to bring the desired periodic reflection series up out of the background. In all cases the tuning is highly damped in order to prevent false records from shock excitation.

—However, in order to permit the study of the particular wave forms of the echoes from the different obstructions, it is desirable to record the

Defendant's Exhibit L—(Continued)

echoes without the accenting of the periodically recurring echoes from the tubing collars or pipe joints, which accenting tends to somewhat distort the precise wave pattern and for this purpose a switch S may be provided in a shunt circuit extending about the reactance 68 and condenser 69 which will when closed eliminate from the system the tuning or accenting effects.

—Also one or more stages of amplification may be added in advance of the recorder 30 for the purpose of amplifying the signals received sufficiently to give a desired fluctuation of the recording beam.—

Page 15, Lines 1 and 2, cancel "copending application" and substitute—Patent No. 2,156,519—.

Page 17, Line 1, cancel "upon the diaphragm 17" and substitute—thereupon—.

Claim 29, Line 11, before "alternating" cancel "said"; Line 16, before "means" insert—electrical echo accenting—; Line 18, change "tuning" to read —causing—; same line, before "echoes" insert—periodically recurring—; Line 19, change "selected obstructions" to read

D6

—a series of similar obstructions spaced substantially uniformly along the well—.

Cancel Claims 23, 24, 25 and 30.

Add the following claims:

D7

—31. In a system for receiving and translating

Defendant's Exhibit L—(Continued)

pressure echoes from a well, a microphone adapted to translate pressure variations impinging thereon to corresponding impedance variations, means coupling said microphone to said well to expose said microphone to gas pressure in the well, a circuit including a source of alternating current of a frequency many times greater than the frequency of the echoes desired to be translated, said circuit including said microphone so disposed therein as to vary the impedance of said circuit and to therefry or amplitude

by vary ∧ said alternating current in accordance with the pressure variations impinging on said microphone, means coupled to said circuit and responsive to variations of said alternating current in said circuit for describing an observable wave pattern reproduction of the pressure variations in said well, electrical echo accenting means interposed between said microphone and said last named means for causing said system to respond more readily to periodically recurring echoes from a series of similar obstructions spaced substantially uniformly along the well than to pressure variations emanating from other sources, and means associated with said accenting means and operable at will for imposing said accenting means upon said system or for removing the effect of said accenting means from said system.

—32. In a system for receiving and translating pressure echoes from a well, a microphone

Defendant's Exhibit L—(Continued)

adapted to translate pressure variations impinging thereon to corresponding impedance variations, means coupling said microphone to said well to expose said microphone to gas pressure in the well, a circuit including a source of alternating current of a frequency many times greater than the frequency of the echoes desired to be translated, said circuit including said microphone so disposed therein as to vary the alternating current therein in accordance with pressure variations impinging on said microphone, rectifying means coupled to said circuit to produce a direct current, the amplitude of which varies in accordance with the varied alternating current in said circuit, and means coupled to said rectifier and responsive to variations in the amplitude of said direct current for describing an observable wave pattern reproduction of the pressure variations in said well.

—33. In a system for receiving and translating pressure echoes from a well, a microphone adapted to translate pressure variations impinging thereon to corresponding impedance variations, means coupling said microphone to said well to expose said microphone to gas pressure in the well, a circuit including a source of alternating current of a frequency many times greater than the frequency of the echoes desired to be translated, said circuit including said microphone so disposed therein as to vary the alternating current therein in accordance with pressure variations impinging on said microphone, means coupled to said circuit and

Defendant's Exhibit L—(Continued)

responsive to variations of said alternating current in said circuit for describing an observable wave pattern reproduction of the pressure variations in said well, and means associated with said circuit for adjusting the natural period of oscillation of said circuit to produce a direct current from said rectifier approximately midway between the normal operating maximum and minimum values when said microphone is subjected only to static pressures.

—34 In a system for receiving and translating pressure echoes from a well, a microphone adapted to translate pressure variations impinging thereon to corresponding impedance variations, means coupling said microphone to said well to expose said microphone to gas pressure in the well, a circuit including a source of alternating current of a frequency many times greater than the frequency of the echoes desired to be translated, said microphone being so disposed in said circuit as to vary the normal high frequency of the current imposed on the circuit by said source in accordance with the pressure variations impinging on said microphone, a resonant circuit coupled to receive alternating current from said first circuit and tuned to a fixed frequency which ($\wedge E^1$) ~~is either slightly more than the maximum or slightly less than the minimum frequency~~ caused in said first circuit by said pressure variations, whereby the magnitude of current in said resonant circuit is varied in accordance with said pressure variations, and means coupled to said re-

Defendant's Exhibit L—(Continued)

sonant circuit and responsive to variations in the magnitude of said alternating current for describing an observable wave pattern reproduction of the pressure variations in said well.

—35. In a system for receiving and translating pressure echoes from a well, a microphone adapted to translate pressure variations impinging thereon into variations of electric current, means coupling said microphone to said well to expose said microphone to gas pressure in the wall, means responsive to variations of said electric current for describing an observable wave pattern reproduction of the pressure variations in said well, and electric circuit including said microphone and said current responsive electrical tuning means means, and ∧ ~~accenting means~~ interposed in said circuit between said microphone and said current current responsive means responsive means for causing said ~~system~~ ∧ to respond more readily to periodically recurring echoes from a series of similar obstructions spaced substantially uniformly along the well than to echoes from pressure variations emanating from other sources.—

REMARKS

Subsequent to making the amendment of October 17, 1940, this application has been carefully reviewed and it has been found that in a number of places in the specification somewhat inapt language was originally selected for the description of the various devices disclosed and that in order that

Defendant's Exhibit L—(Continued)

the disclosure be accurate and more readily understandable, it is desirable to make changes in the language used as noted in the amendments inserted herewith.

For example, in the Office action of April 22, 1940 it is noted that the Examiner raised several questions with reference to the operation of the systems described and while it was believed that the amendments made in the amendment of October 17, 1940 sufficiently answered these questions, the foregoing amendments made herewith will be of considerable assistance to those who may read this description in the future.

For example, where "wave pattern" is used, it is desirable to point out that this wave pattern is "pressure-time pattern" which is described by either the beam of light on the screen 36 or by the beam of light upon the record tape 35, thus eliminating any possibility of confusion as to the character of the wave pattern referred to.

It is also noted that where in the original specification it was stated that the impulse is "reflected by the various obstructions", it would be more accurate to say that the impulse is "partially reflected by each of the obstructions", which change has been made.

The last few lines of the first paragraph on Page 6 have been corrected to make them read more coherently.

On Page 11 the effect and operation of the condensers 56 employed to vary the sensitivity of the

Defendant's Exhibit L—(Continued)

microphone upon the system has been more fully brought out.

On Page 12 it was noted that there was a reversal of the correct arrangement described and this has been changed to make it accurate.

On page 14 the description has been elaborated to more fully answer the Examiner's question raised in the third paragraph of the last Office action, while at the lower end of Page 14 a paragraph has been inserted to describe more completely the effect of the tuning for the periodically recurring tubing collar echoes.

The Examiner is requested to add the reference character "S" to the switch shown in each of Figs. 2, 4 and 5, as indicated on the accompanying print.

With regard to the claims now remaining in this application, this case has been carefully reviewed and the claims revised so that there is now presented a minimum number of claims to adequately cover the subject matter.

As pointed out in the amendment of October 17, 1940, new Claims 26 and 27 are generic to all of the forms of the circuit shown in Figs. 2, 4 and 5.

Claim 28 is generic to all of the forms of the circuit shown in Figs. 2, 4 and 5 with the additional limitation of the inclusion of the impedances 56 (or 66) in series and in parallel with the microphone to vary the sensitivity of the system.

Claim 29 is generic to all of the circuits and includes as an additional feature the accenting of

Defendant's Exhibit L—(Continued)

such periodically recurring echoes such as echoes of the more or less uniformly spaced tubing collars or casing joints such as by using the tuning apparatus 68-69 associated with any one of the circuits.

Claim 31 is directed to the same subject matter as Claim 29 and includes the feature of tuning the system to accent the tubing collar or other periodically recurring echoes and with the additional limitation of the feature of eliminating this tuning when it is desired to particularly study the unaccented and undistorted wave forms produced as a part of the wave pattern. This is the switch S which is shown shunted about the tuning devices 68 and 69.

New Claim 32 has been substituted for a portion of old Claim 24, this claim being directed now to the generic features of all of the circuits with the additional limitation of employing a rectifier system for translating the current variations in the circuit into variations of amplitude of a direct current which is capable of being passed to the galvanometer and recording apparatus.

Claim 33, which has been substituted for Claim 24, is now presented drawn generically to all of the circuits and including the tuning or adjustment of the system to a mid point between maximum and minimum values when the microphone is subject only to static pressures.

All of Claims 27, 28, 29, 31, 32 and 33 are therefore generic to all of the forms of the invention shown in this application.

Defendant's Exhibit L—(Continued)

Old Claims 21 and 22 have been left in the application as being specific to the circuit arrangement shown in Fig. 2.

New Claim 34 has been inserted specific to Fig. 4.

Old Claim 17 has been left in this application as being specific to Fig. 5.

New Claim 35 inserted herewith has been directed broadly to the features of translating the pressure variations into alternating current variations, which alternating current variations are then translated into a reproduction of the wave pattern but with the accenting of the periodically recurring echoes such as from tubing couplings. This is a geature which is generic to all of the forms of circuit hown and which is clearly patentable over any of the prior art which has been cited in this application.

The total number of claims in this case has been now limited to twelve and each of these claims has been directed to a particular feature of the applicant's system as disclosed, which features are not contemplated in any of the prior art.

It is believed that this amendment will materially assist in advancing the prosecution of this case toward final conclusion and that each of the claims as presented will be found to be allowable.

An early favorable action is respectfully requested

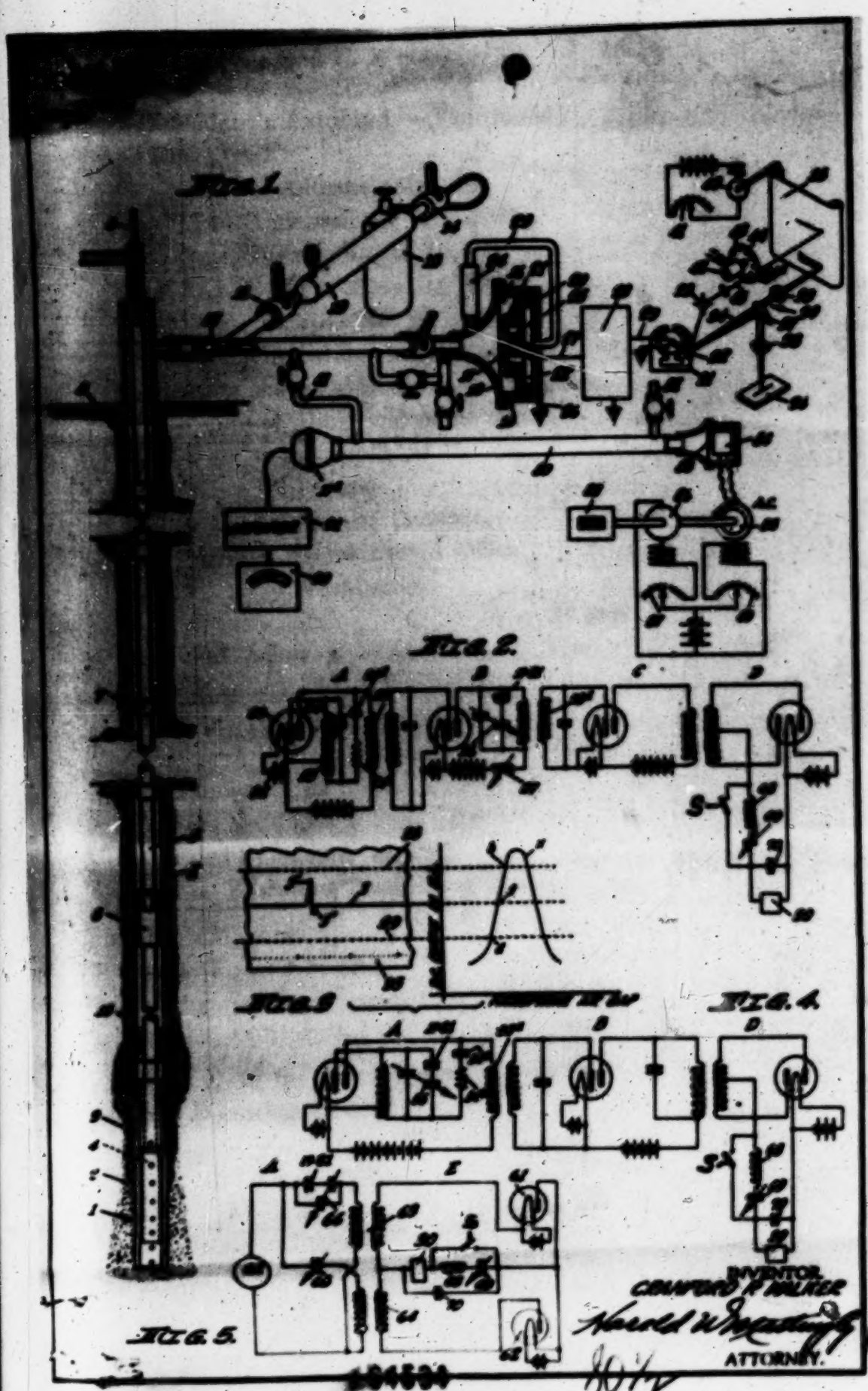
Respectfully submitted,

HAROLD W. MATTINGLY

Attorney for Applicant

HWM:MM

Encl.


FIG. 1.
FIG. 2.
FIG. 3.
FIG. 4.
FIG. 5.
INVENTOR
CLIFFORD F. HOLMES
Harold W. Ingraham
ATTORNEY.

Defendant's Exhibit L—(Continued)

Div. 42 Room 5882

Address only
"The Commissioner of Patents,
Washington, D. C.,"
and not any official by name

Paper No. 10

All communications respecting this
application should give the serial number,
date of filing, and name of
the applicant

260

Department of Commerce
United States Patent Office
Washington

Mar 29 1941

Please find below a communication from the Examiner in charge of this application.

CONWAY P. COE
Commissioner of Patents,

Applicant: Cranford P. Walker
Ser. No. 164,534
Filed September 18, 1937
For Vibration Translating Means

Harold W. Mattingly,
924 Pacific Finance Bldg.,
621 S. Hope Street,
Los Angeles, California.

Responsive to the amendments filed October 19, 1940, and December 23, 1940:

Defendant's Exhibit L—(Continued)

Added reference:

British 459,723 Lance et al Acc. Jan. 13, 1937 179-171 G(o) (4 pp. spec.; 1 sh. dwg.)

It appears from the British patent cited that it has long been known in the vacuum tube arts that a very low frequency wave could be amplified with great fidelity by modulating a carrier wave with the low frequency wave and rectifying the resultant modulated wave to yield the original low frequency wave. The type of modulation circuit used is apparently immaterial as any type of carrier wave modulator will serve for the purpose.

Upon reconsideration, therefore, claims 17, 21, 22, and 26 through 34 inclusive are rejected on the ground that there would be no invention in applying the idea of carrier wave modulation of low frequencies to the seismic art, in view of the state of the amplifier art as disclosed by British patent 459,723.

The system of Lehr 2,047,974, or any other similar prior art system could without invention be provided with an amplifier of the type described in the British patent (note especially lines 17-27 and 45-53 of page 1 of the provisional specification of the British patent). Espenschied 1,428,156 shows one type of carrier wave modulating circuit used for fidelity of amplification of low frequency waves but any other known type of carrier wave modulator could, without invention, be used instead.

Claim 35 is rejected as defining nothing patentable over Walter 2,156,519. The Walker patent

Defendant's Exhibit L—(Continued)

discloses means for tuning mechanically to the selected echo, but it is obvious that electrical tuning could be used instead in a system comprising an electrical receiving circuit. The two species are not patentably different.

Claim 34 is rejected as alternative in line 14.

H. MARANS,
Acting Examiner.

J.D.S.:dc

Submitted Mar 26 1941. Supervisory Examiner.

Division 42, Paper No Sep 26 1941 U. S. Patent Office.

Mail Division Sep 25 1941 U. S. Patent Office.

In the United States Patent Office
Division 42 — Room 5882
Via Air Mail
Confirmation
Regular Mail

Cranford P. Walker
Vibration Translating Means
Filed September 18, 1937
Serial No. 164,534

Los Angeles, California
September 23, 1941

Hon. Commissioner of Patents
Washington, D. C.

Sir:

In response to the office action of March 29, 1941,

Defendant's Exhibit L—(Continued)

please amend the above identified application as follows:

Claim 34, cancel from "is" in Line 14 through "frequency" in Line 15 and substitute:

E1

—is slightly outside of the range between the maximum and minimum frequencies—.

Claim 35, Line 9, after "and", second occurrence, insert —electrical tuning means—;

Line 10, cancel "accenting means";

Line 12, change "system to read —current responsive means—.

Add the following claim:

E2

—36. In a system for receiving and translating pressure echoes from a well, a microphone adapted to translate pressure variations impinging thereon to corresponding impedance variations, means coupling said microphone to said well to expose said microphone to gas pressure in the well, a circuit including a source of alternating current of a frequency many times greater than the frequency of the echoes desired to be translated, said circuit including said microphone so disposed therein as to vary the alternating current therein in accordance with pressure variations impinging on said microphone, rectifying means coupled to said circuit to produce a direct current, the amplitude of which varies in accordance with the varied alternating current in said circuit, means coupled to said rectifier and responsive to variations in the amplitude of

Defendant's Exhibit L—(Continued)

said direct current for describing an observable wave pattern reproduction of the pressure variations in said well, and means interposed between said rectifier and said last named means for accenting the periodically recurring echoes from a series of similar obstructions spaced substantially uniformly along the well over other echoes from pressure variations emanating from other sources.—

REMARKS

Reconsideration of all of the claims in this application is respectfully requested. Insofar as it is possible to understand the last Office action, the Examiner has taken the position that because a British patent shows that it is old and well known to amplify a very low frequency wave by modulating a carrier wave with the low frequency wave and rectifying the resultant modulating wave, then no application of this principle to specific apparatus for performing a specific result can ever thereafter be patentable.

The fallacy of this line of reasoning becomes immediately apparent if the Examiner will consider that this same line of reasoning would prevent the patenting of any combination of pieces of old mechanism put together to perform a specific and new result.

The applicant in devising this system started out on the basis that by measuring the pressure waves emanating from the echoes in a well could be employed to describe or record an observable wave

Defendant's Exhibit L—(Continued)

pattern in which the separate echoes from different types of obstructions in the well could be readily distinguished from each other so as to permit a person studying these wave patterns or records to definitely determine which of the peaks resulted from echoes from tubing joints, which of the echoes resulted from a tubing catcher and which of the echoes resulted from the surface of the liquid in the well.

How to describe or record the desired wave pattern with a maximum of accuracy and fidelity was the problem which was presented to this inventor. After trying many other methods, including the methods described in the Walker patent No. 2,156,519, he devised the arrangements disclosed in the present application as being a satisfactory solution for his problem.

True, this inventor did not invent a system of modulating a high frequency carrier wave and then rectifying the resultant modulated wave nor is he claiming such system broadly.

The inventor does assert and does claim to have invented that combination by which he adapts a low frequency modulation of a high frequency carrier wave and a rectification of the resultant modulated wave and the accenting of certain of the low frequencies either before or after rectification to solve his particular problem of translating the complex but low frequency gas pressure waves resulting from echoes within an oil well into an accurate rec-

Defendant's Exhibit L—(Continued)

ord or chart of the shapes of the wave patterns so as to produce the character of record which upon study and analysis produces the information which is of such great value in accomplishing the objects for which this echo system has substantially supplanted all other methods of obtaining fluid levels, fluid pressures, fluid densities and production capacities of oil wells.

Again it is repeated that the applicant is not claiming that he is the inventor of a modulated carrier wave system but he is claiming and has accurately defined in the claims a combination of apparatus including a modulated carrier wave system by which he can produce with great accuracy and great fidelity a particular desired result.

To deny this applicant protection upon his particular combination by finding a portion of the system claimed in the Lehr patent No. 2,047,974, another portion or a suggestion in this inventor's own earlier patent, and then to have to seek in a third patent (the British patent) other portions of the claimed system is an attempt on the part of the Examiner to build up from these separate sources a teaching which is not contained in any one of them nor is there any teaching in all of these patents how this applicant could solve the problem which confronted him. This line of reasoning on the part of the Examiner is one in which the Examiner, after seeing applicant's disclosure and the way in which applicant has solved his problem, then assumes that because this piece and that piece and

Defendant's Exhibit L—(Continued)

another piece of the apparatus claimed was old that it would not involve invention to take these old pieces and to put them together in the manner which applicant has for the first time disclosed and taught.

The Examiner must admit that the Lehr patent No. 2,047,974 does not teach how to accurately reproduce a wave pattern in which the various echoes from different obstructions can be distinguished from each other in the record which Lehr produced. It is equally obvious that there is nothing in the Lehr disclosure which would teach either the desirability nor how to accomplish the accenting of tubing collar echoes or other periodically recurring echoes. Most certainly there is nothing in the Lehr disclosure which would teach how or where in the system to impose the accenting.

The Examiner must therefore admit that to merely substitute the modulation circuit or modulation system described or hinted at in the British patent No. 459,723 would not accomplish the results which the applicant seeks and which applicant claims and that to adapt such modulation system to applicant's purpose required the applicant to exercise invention of a high order.

Likewise the Examiner must admit that while applicant in his prior patent No. 2,156,519 describes the desirability for accenting the tubing collar echoes and discloses a mechanical arrangement for accomplishing this result, this disclosure would cer-

Defendant's Exhibit L—(Continued)

tainly not defeat applicant's right to obtain claims upon other specific ways of producing this desirable accenting result.

The Examiner also must admit that this applicant is clearly entitled to a protection upon other specific arrangements for producing this accenting electrically in an electrical translation system as distinguished from a mechanical translation system.

Applicant admits that the broad idea of electrical tuning for tubing collar echoes is the full mechanical equivalent of the mechanical means which applicant disclosed in his earlier patent.

Where the Examiner falls into error is that applicant is not in his claims attempting to cover the broad idea of electrical accenting but instead he is seeking protection upon a specific arrangement and a specific location of his electrical accenting mechanism.

It is therefore respectfully requested that the Examiner reconsider each of the claims of this application and to carefully analyse each of these claims. Applicant is confident that upon making such careful analysis the Examiner will find that each of the claims presented in this application is directed to, not merely the broad idea of translating gas pressure waves in the well into a record of the pressure waves, not merely the broad idea of imposing electrical tuning or accenting for bringing out the registration of selected recurring echoes, but instead a particular arrangement of circuits

Defendant's Exhibit L—(Continued)

and tuning means by which he accomplishes that result.

Claim 34 has been amended to correct the objectionable feature pointed out by the Examiner while Claim 35 has been amended to more clearly distinguish applicant's electrical accenting mechanism from the mere mechanical equivalent or broadly electrically accenting or tuning instead of mechanical accenting or tuning, as was disclosed in applicant's earlier patent.

New Claim 36 is presented to cover the particular location of applicant's tuning and filtering devices such as 68, 69, 70 as being interposed between the rectifier and the wave pattern describing device such as 31 to set forth even more specifically that form of tuning or accenting for the periodically recurring echoes.

It is believed that upon making the reconsideration and analysis requested herein the Examiner will withdraw the character of rejection entered in the last Office action and will find each of the claims presented to be allowable. If upon this reconsideration the Examiner feels that such rejection should stand, he is respectfully requested to make such rejection final so that an immediate appeal may be taken.

Respectfully submitted,

HAROLD W. MATTINGLY

Attorney for Applicant.

HWM:MM

Defendant's Exhibit L—(Continued)

Div. 42—Room 5882.

260

DEPARTMENT OF COMMERCE

United States Patent Office
Washington
Address only
"The Commissioner of Patents
Washington, D. C."
and not any official by name
Paper No. 12
All communications respecting this
application should give the serial number,
date of filing, and name of
the applicant

Jan 14 1942

Please find below a communication from the EXAMINER in charge of this application.

CONWAY P. COE
Commissioner of Patents.

Applicant: Cranford P. Walker
Ser. No. 164,534
Filed September 18, 1937
For Vibration Translating Means

Harold W. Mattingly,
924 Pacific Finance Building,
621 S. Hope Street,
Los Angeles, California.

Responsive to the amendment filed September 25, 1941:

Defendant's Exhibit L—(Continued)

Of interest:

1,780,567 Rieber Nov. 4, 1930 177-352.7x

Claims 17, 21, 22, 26 through 34 and 36 appear to be allowable.

The rejection of claim 35 as defining nothing patentable over prior art systems is repeated. Since applicant is not the first to utilize an electrical receiving circuit to receive well echoes, the examiner is still of the opinion that in view of Walker 2,156,519 there would be no invention in using tuning means in the electrical circuit between the echo receiving means and the recording means. Applicant's argument with regard to the specific location of the accenting mechanism has been considered. The normal method of electrically accenting one of a plurality of received frequencies is by a tuned circuit such as applicant uses. It is old to do the tuning at the recording point; this is shown, for example, in Rieber in which seismic echoes are received by the use of a carrier wave to derive an observable wave pattern reproduction of the echoes, and an echo of a desired frequency is accented in the receiving circuit after the carrier wave has been rectified.

The foregoing action closes the prosecution of the case before the Examiner. Any amendment of request for reconsideration which on inspection is found to require reexamination of the case will not be entered, but, if promptly filed, may be given consideration a reasonable time prior to the expira-

Defendant's Exhibit L—(Continued)

tion of the statutory period. (See ex parte Peterson, 1928 C. D. 31.)

This rejection is made FINAL.

H. P. CUTTING
Examiner.

JDS.
JDS:dc

1937

CONTENTS

1. Application .....papers.
2. Print Sept. 23/37
3. Rejection Jan 17 1938
4. Amdt. A July 15, 1938
5. Rejection Apr 5 1939
6. Amdt. B Oct. 2, 1939.
7. Rejection Apr 22 1940
8. Amdt C Oct. 19, 1940
9. Amdt. D Dec. 23, 1940
10. Rejection Mar 29 1941
11. Amdt. E Sept. 25, 1941.
12. Final Rejection Jan 14 1942

Defendant's Exhibit L—(Continued)
In the United States Patent Office
Div. 42

In re application of:

CRANFORD P. WALKER

Ser. No. 164,534
Filed September 18, 1937

VIBRATION TRANSLATING MEANS

* * * * * * *

Hon. Commissioner of Patents,
Washington, D. C.

Sir:

REQUEST FOR FURTHER EXPLANATION

Applicant notes the entry of the Office action of January 14, 1942 in which claim 35 was rejected as defining nothing patentable over the prior art systems, particularly over the Walker patent 2,156,519 apparently on the ground that the electrical tuning defined in claim 35 is the mechanical equivalent of the mechanical tuning shown in the earlier Walker patent.

However, the Rieber patent referred by the Examiner does not disclose electrical tuning nor does it indicate that electrical tuning is the mechanical equivalent of Walker's earlier mechanical arrangement, since the Rieber patent shows the tuning as being accomplished by the mechanical tightening or loosening of the "string" on his string galvanometer.

Defendant's Exhibit L—(Continued)

Under these circumstances it is believed that the rejection of claim 35 should be withdrawn unless the Examiner can find a reference patent which demonstrates that the mechanical tuning and electrical tuning are considered as interchangeable and as the mechanical equivalent of each other.

It is requested therefore that before closing the prosecution of this case the Examiner reconsider the rejection of claim 35 for the reasons indicated above.

Respectfully submitted,

HAROLD W. MATTINGLY

Attorney for Applicant.

Washington, D. C.,
April 6, 1942.

(Copy)

Div. 42, Room 308 Paper No. 14

DEPARTMENT OF COMMERCE

Richmond, Va.

Applicant: Cranford P. Walker
Serial No. 164,534
Filed Sept. 18, 1937
For Vibration Translating Means.
Mailed April 11, 1942

Harold W. Mattingly
621 South Hope Street
Los Angeles, California

Responsive to the letter of April 6, 1942.

Defendant's Exhibit L—(Continued)

Attention is directed to

1,498,238 Holland June 17, 1924 177-314x

The equivalence of electrical tuning and mechanical tuning for selective reception was thought to be so generally recognized that citation of an illustrative reference was not considered necessary. In view of applicant's request for further explanation, however, the Holland patent is referred to as one illustration of the interchangeability of mechanical and electrical tuning for selection purposes. Fig. 2 shows the use of mechanical tuning means while Fig. 3 shows the use of electrical tuning means for the selective operation of the signal S through relay winding 18.

This application stands under the final rejection of Jan. 14, 1942.

Examiner.

Defendant's Exhibit L—(Continued)
(Copy)

In the United States Patent Office
Division 42—Room 308

CRANFORD P. WALKER
VIBRATION TRANSLATING MEANS

Filed September 18, 1937
Serial No. 164,534

Los Angeles, California
July 7, 1942

Hon. Commissioner of Patents
Washington, D. C.

Sir:

In response to the Office actions of April 11, 1942 and January 14, 1942, please amend the above identified application as follows:

Cancel Claim 35.

Claim 36, next to the last line, cancel "other echoes from".

In preparing the application for issue, please renumber the claims as follows:

Claim	26	to	become	Claim	1
"	27	"	"	"	2
"	28	"	"	"	3
"	29	"	"	"	4
"	31	"	"	"	5
"	32	"	"	"	6
"	33	"	"	"	7
"	21	"	"	"	8
"	22	"	"	"	9
"	34	"	"	"	10
"	17	"	"	"	11
"	36	"	"	"	12

Defendant's Exhibit L—(Continued)

REMARKS

The foregoing amendment to Claim 36 has been made since upon reading this claim it is found that the last two lines of this claim included a redundancy which made the claim inaccurate. The claim should recite the accenting of the periodically recurring echoes over pressure variations emanating from other sources and the words "other echoes from" are not only unnecessary but are a double inclusion of echoes and the pressure variations resulting from such echoes.

Upon reviewing the claims it is believed that the claims will appear in better order in the issued patent if renumbered and arranged as requested above.

The cancellation of Claim 35 places this case in condition for immediate allowance, which action is respectfully requested.

Respectfully submitted,

HAROLD W. MATTINGLY
Attorney for Applicant

HWM:MM

(Copy)

Div. 42 Paper No. 16

Department of Commerce
Richmond, Va.

Applicant: Cranford P. Walker
Ser. No. 164,534
Filed Sept. 18, 1937
For Vibration Translating Means
Mailed July 22, 1942

Defendant's Exhibit L—(Continued)

Harold W. Mattingly
621 S. Hope Street
Los Angeles, California

In accordance with the provisions of Order No. 2308, dated March 12, 1917, which reads in part as follows:

> Obvious informalities in the application may be corrected by the Examiner, but said correction must be in the form of an amendment, approved by the Principal Examiner in writing, placed in the file, and made a part of the record. The changes specified in the amendment will be entered by the clerk in the regular way.

the changes, hereinafter specified, are made by the examiner in the application above identified.

Should these changes not be satisfactory to the applicant, appropriate amendment may be proposed under the provisions of Rule 78, provided the specification has not been printed.

The application has been amended as follows:

Page 11, line 2, after "will' insert —cause it to—.

Page 13, line 12, insert —and— before "is".

Renumbered claim 11, line 3, singularize "impedances".

Examiner.

[Endorsed]: Filed Nov. 10, 1942.

O-2

DEFENDANT'S EXHIBIT O-2

Patent No. 602,422 Dated: Apr. 19, 1898

To

B. C. BATCHELLER

For

APPARATUS FOR LOCATING OBSTRUCTIONS IN TUBES

[Endorsed]: Filed Nov. 4, 1942.

(No Model.) 2 Sheets—Sheet 2.

B. C. BATCHELLER.

APPARATUS FOR LOCATING OBSTRUCTIONS IN TUBES.

No. 602,422. Patented Apr. 19, 1898.

FIG. 3.

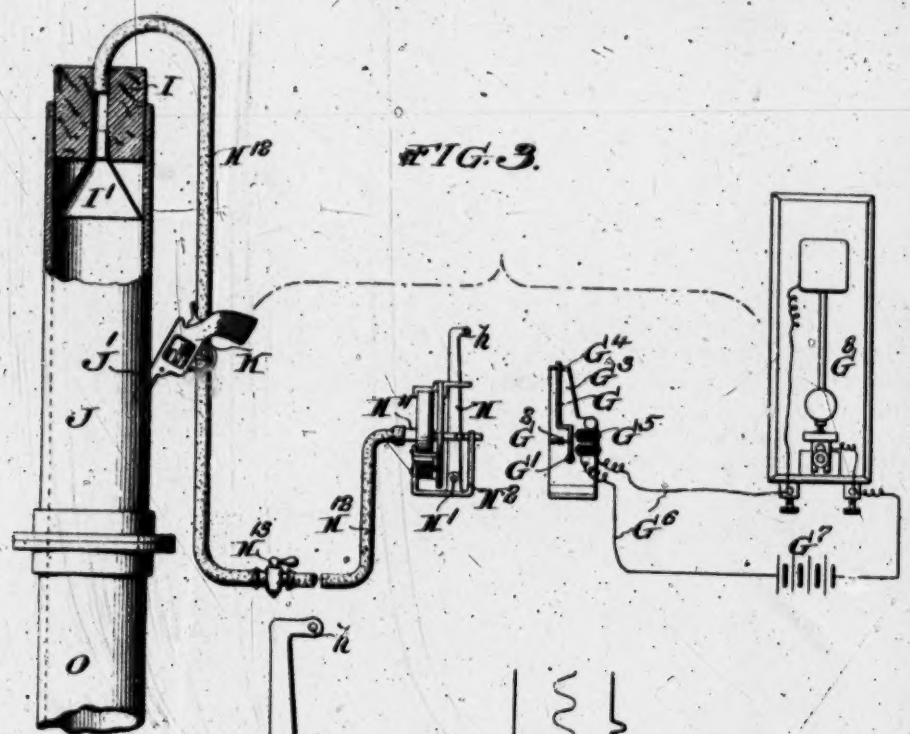


FIG. 4.

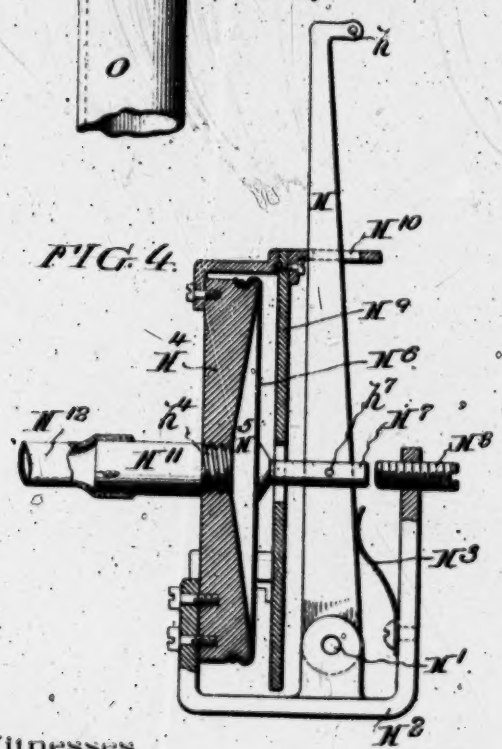
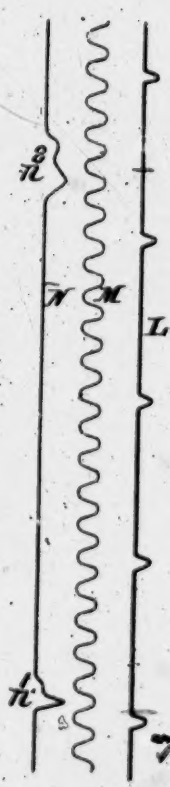


FIG. 5.



Witnesses.

Inventor.
Benjamin C. Batcheller
by Thomas J. Chambers
his Attorney.

1068

(No Model.) 2 Sheets—Sheet 1.

B. C. BATCHELLER.

APPARATUS FOR LOCATING OBSTRUCTIONS IN TUBES.

No. 602,422. Patented Apr. 19, 1898.

FIG. 1.

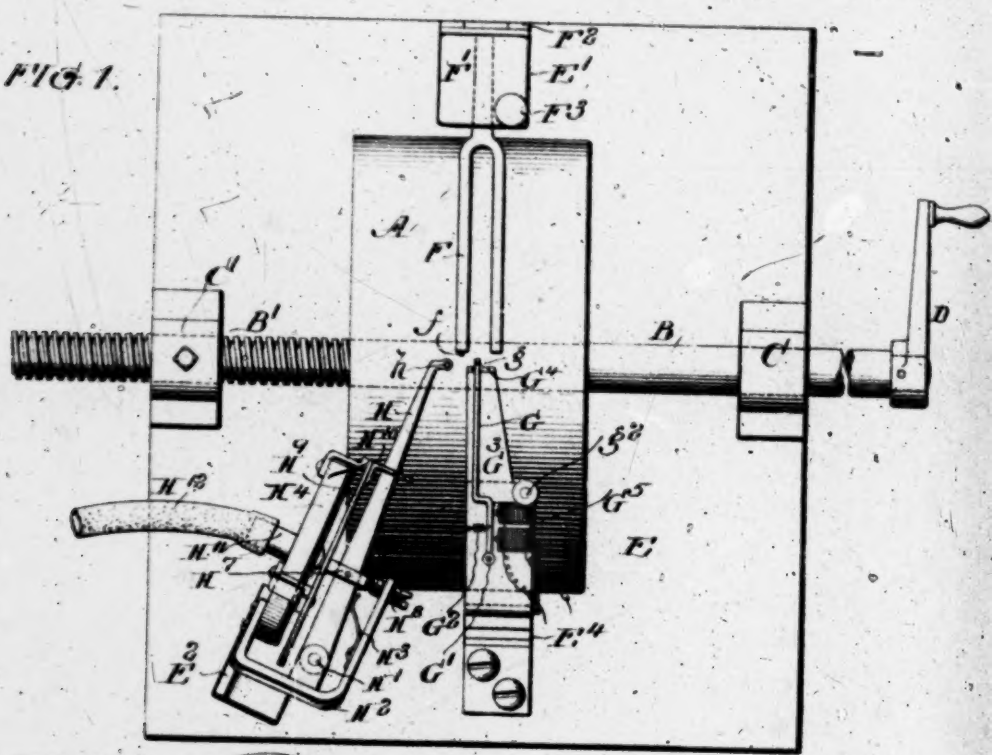
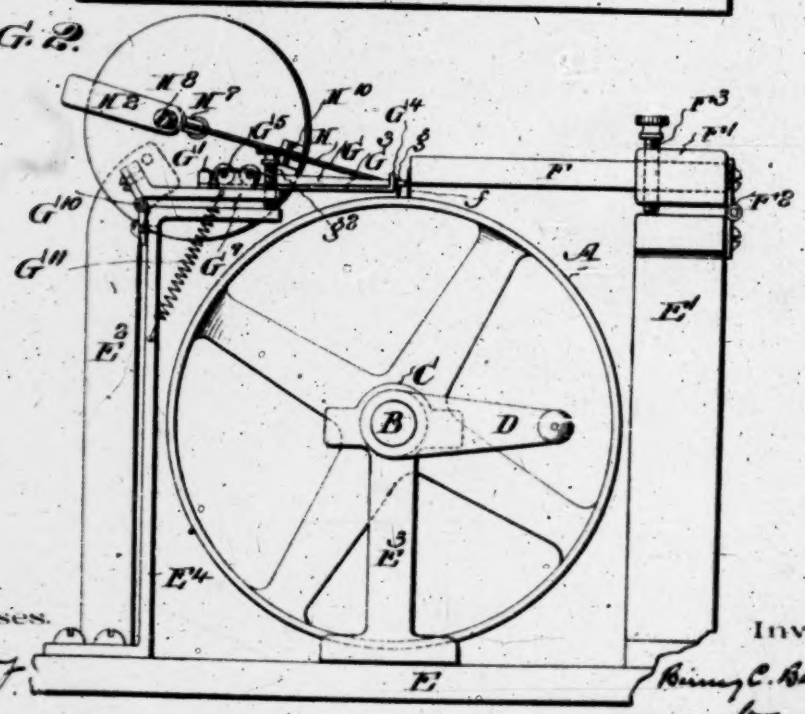


FIG. 2.



Witnesses.
Harry Drury
D. Stewart

Inventor.
Binney C. Batcheller
by Francis T. Chambers
his Attorney.

UNITED STATES PATENT OFFICE.

BIRNEY C. BATCHELLER, OF PHILADELPHIA, PENNSYLVANIA.

APPARATUS FOR LOCATING OBSTRUCTIONS IN TUBES.

SPECIFICATION forming part of Letters Patent No. 602,422, dated April 19, 1898.

Application filed September 28, 1897. Serial No. 653,340. (No model.)

To all whom it may concern:

Be it known that I, BIRNEY C. BATCHELLER, a citizen of the United States of America, residing in the city and county of Philadelphia, in the State of Pennsylvania, have invented a certain new and useful Improvement in Methods of and Apparatus for Locating Obstructions in Tubes, of which the following is a true and exact description, reference being had to the accompanying drawings, which form a part thereof.

My invention relates to a new method for locating obstructions in pneumatic or other tube systems and to improved mechanism especially adapted for carrying my mechanism into practical use.

It has heretofore been attempted with varying degrees of success to locate obstructions in long tubes by ascertaining and recording the lapse of time intervening between the creation of a sound impulse in the tube at a certain point and the reflection or echo of the said sound returning to the said point after being reflected from the obstruction in the tube. The velocity of the sound-wave being a known factor, it is easy to compute from the data thus obtained the distance of the obstruction from the point in the tube at which the test is made.

My invention is an improvement upon the method briefly described above; and in its main feature it consists in wholly or partly closing the connection from the tube to be tested to the sound and time recording apparatus at the time when the sound impulse is created in the tube and then fully and freely opening the said connection before the echo or reflection of the said sound returns to the point in the tube where the test is made, my purpose being to avoid an undue and disruptive shock to the recording apparatus, such as would be apt to occur if the recording apparatus was in full connection with the tube at the time the sound is made and at the same time to cause the weaker reflected sound to act directly and with full force upon the recording apparatus.

In carrying my invention into effect I have devised a connection between the tube and the recording apparatus of such a character or provided with such appliances that it may be partially or wholly closed when the impulse is created and freely and entirely open before the return of the echo or reflected sound-wave. Another useful and valuable feature of my invention consists in protecting the diaphragm, to which the sound-waves are communicated and through which they are transmitted to the recording mechanism, against undue and disruptive shock by placing in front of it a shield or protecting-plate, against which it is impelled in the event of its being exposed to a dangerous sound impulse and by means of which its outward movement to a disruptive point is prevented.

The nature of my improvements will be best understood as described in connection with the drawings, in which it is illustrated, and in which—

Figure 1 is a plan view of the recording apparatus; Fig. 2, a side elevation of the same; Fig. 3, a diagrammatic illustration of the various appliances making up the recording apparatus and connected therewith and all of the means for connecting the recording apparatus with the tube and for creating a sound impulse in the tube. Fig. 4 is an enlarged sectional view of the sound-recording diaphragm and its immediate connections, and Fig. 5 a diagrammatic illustration of the record made by the appliances shown when in operation.

A is a cylinder having a smooth surface, which in use is coated with lampblack or some other film upon which a light stylus will make a visible impression. This cylinder is secured to a shaft B, threaded at one end, as indicated at B', and resting in convenient bearings, as indicated at C and C', bearing C being threaded to engage the threaded portion of the shaft B.

D is a crank by which the shaft and cylinder can be turned, and obviously as they turn they are by the action of the screw B' longitudinally and gradually moved. While I have indicated a crank as a convenient device for rotating and moving the cylinder, it will of course be understood that any convenient driving apparatus may be substituted therefor. As shown, the cylinder is mounted on a base E, the bearings C and C' being supported on standards E^3, extending up from the side piece, and other standards, as indicated at E', E^2, and E^4, being provided

as supports for the appliances hereinafter described.

F is a tuning-fork of known pitch, having a light stylus (indicated at *f*) attached to one of its prongs in position to rest lightly on the cylinder A. The tuning-fork, as shown, is attached to a block F', hinged to the standard E' at F², an adjusting-screw F³ serving to adjust the pressure with which the stylus *f* will rest against the cylinder A. In practice I may state I have used a tuning-fork giving the note "C" of the musical scale and having a known rate of five hundred and twelve single vibrations per second. The wave-line produced by the stylus produced by the said tuning-fork is diagrammatically illustrated at M in Fig. 5, each single vibration thus recorded measuring one five hundred and twelfth ($\frac{1}{512}$) of a second.

G is a light rod pivotally supported on a block G', hinged at G¹⁰ to the standard E' and adjustable in height by means of the adjusting-screws *g*². An extension G², having a turned-up and slotted end G⁴, serves to support the outer end of the light lever or rod G, to which is attached the stylus *g*, the said rod or lever being pivoted at G' to the block G'. A spring G², acting on the lever G, draws it away from an electromagnet, (indicated at G⁵,) said electromagnet when energized overcoming the tension of the spring and drawing the lever G toward it. The energizing of the magnet is conveniently effected at definite time intervals, as indicated in Fig. 3, G⁶ indicating circuit-wires in which is situated a battery G⁷ and a pendulum or equivalent escapement (indicated at G⁸) and by means of which the circuit is closed at definite time intervals. For instance, I have found it convenient to use a pendulum of such length that the circuit will be closed once in each half-second, and the record upon the cylinder A effected by the stylus *g* will be of a character indicated at L in Fig. 5, such a record serving in connection with the tuning-fork record M to greatly facilitate the computation of the total time interval.

The sound-impulse-recording mechanism operates a light pivot-lever H, having at its end a stylus *h*. This lever, as shown, is pivoted to a frame H², supported on the standard E², the pivot being indicated at H', a light spring H³ acting to press the lever H in one direction, as shown in Figs. 1 and 4, and an adjusting-screw H⁸ being provided as an abutment to prevent the movement of the lever H against the spring beyond a definite point. The lever is actuated by a connection H', connected also to a diaphragm H⁶, which is secured to a block H⁴, hollowed out to form a chamber H⁵, into which opens a passage *h*⁴, or rather a tubular connection H¹¹, screwing into the passage *h*⁴. The tubular connection H¹¹ is in turn connected with the tube to be tested conveniently, as shown, by a flexible pipe H¹², opening through a block I, having a funnel-shaped internal opening I', into a pipe-section J, which, as shown, is connected with the tube O to be tested and is formed with an opening J', through which a pistol-barrel can be inserted, K, Fig. 3, indicating the pistol in position to be fired.

It will be understood that an important feature of my method and also of my apparatus is the provision of means whereby the tubular connection between the tube to be tested and the sound-recording apparatus can be partly closed. Any convenient device may be employed for this purpose and among them a cock A¹³, Fig. 3, which is a ready and simple means of partly closing and quickly opening the flexible tube H¹².

In order to further protect the diaphragm H⁶ against disruptive sound-waves, I employ a shield or protecting-plate H⁹, placed in front of it at a distance which will permit of its normal vibration, but which in case of an impulse adapted to have a disruptive effect upon the diaphragm will arrest the motion of the diaphragm and prevent its being forced out beyond a safe limit.

The character of the record made by the stylus *h* is indicated at N in Fig. 5, *n*' indicating the record made at the time the pistol is fired and *n*² the record made on the return of the echoes or reflected wave.

The operation of my device will be readily understood from what has already been said. When a test is to be made, the time-recording apparatus is set in operation, as is also the cylinder A, with the effect of making a record, such as M, or preferably such as M and L. The operator then partially closes the cock H¹³ and fires the pistol K into the pipe-section J, as a result of which a sound-wave is transmitted through the partially-closed connection to the diaphragm H⁶ and by it through the mechanism described to the stylus *h*, which makes a record, as indicated at *n*'. The operator then fully opens the cock H¹³, and upon the return of the echo or reflected sound, which is of course much weaker than the initial sound, its impulse passes freely through the connection to the sound-recording apparatus, the stylus *h* making a record of the return of the sound, as indicated at *n*². The work of calculating the distance of the obstruction against which the sound has been reflected is then simply the coördinated records enabling the operator to ascertain within a very short distance the exact position of the obstruction.

Having now described my invention, what I claim as new, and desire to secure by Letters Patent, is—

1. The method of locating obstructions in tubes which consists in connecting the tube to be tested with an apparatus for recording time-intervals and sound-waves created in the tube, making a loud noise, as by an explosion, in the part of the tube to which the recording apparatus is attached partly closing the connection from the tube to the recording apparatus prior to the making of said loud noise

so as to avoid an undue strain on the
ng apparatus and immediately open-
d connection after the sound impulse
ted in the tube so as to afford a free
e to the recording apparatus for the
impulse reflected from the obstruction
tube.

n an apparatus for locating obstruc-
n tubes—the combination with an ap-
s for visually recording time intervals
ans for coördinately recording sound-
said means being connected with the
o be tested as described and so that
-waves created in said tube will be visu-
ecorded, and means for wholly or par-
interrupting the transmission of the
-waves from the tube to the sound-re-
g device.

In an apparatus for locating obstruc-
in tubes consisting of a device for visu-
ecording time intervals and means for
inately recording sound impulses cre-
in the tube to be tested, the combination
ubular connection leading from the tube to be tested, a diaphragm open to sound impulses coming through said connection, a stylus actuated by said diaphragm to record the sound impulses and means for varying the opening through the tubular connection to the diaphragm.

4. In an apparatus for locating obstructions in tubes consisting of a device for visually recording time intervals and means for coördinately recording sound impulses created in the tube to be tested, the combination of a tubular connection leading from the tube to be tested, a diaphragm open to sound impulses coming through said connection, a stylus actuated by said diaphragm to record the sound impulses and a guard-plate situated in front of the diaphragm arranged to check its outward movement beyond a point of safety.

BIRNEY C. BATCHELLER.

Witnesses:
CHAS. F. MYERS,
D. STEWART.

DEFENDANT'S EXHIBIT O-4

Fessenden Patent No. 1,240,328

[Endorsed]: Filed Nov. 4, 1942.

R. A. FESSENDEN.

METHOD AND APPARATUS FOR LOCATING ORE BODIES.

APPLICATION FILED JAN. 15, 1917.

1,240,328.

Patented Sept. 18, 1917.

Fig. 1.

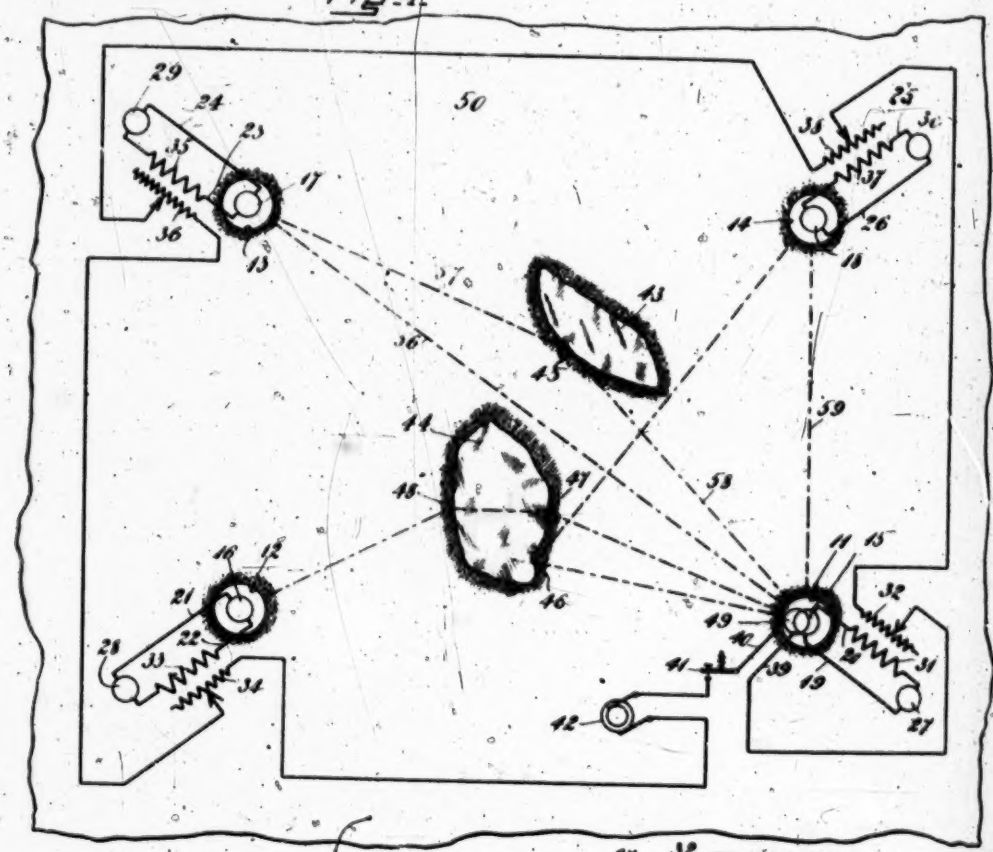


Fig. 2.

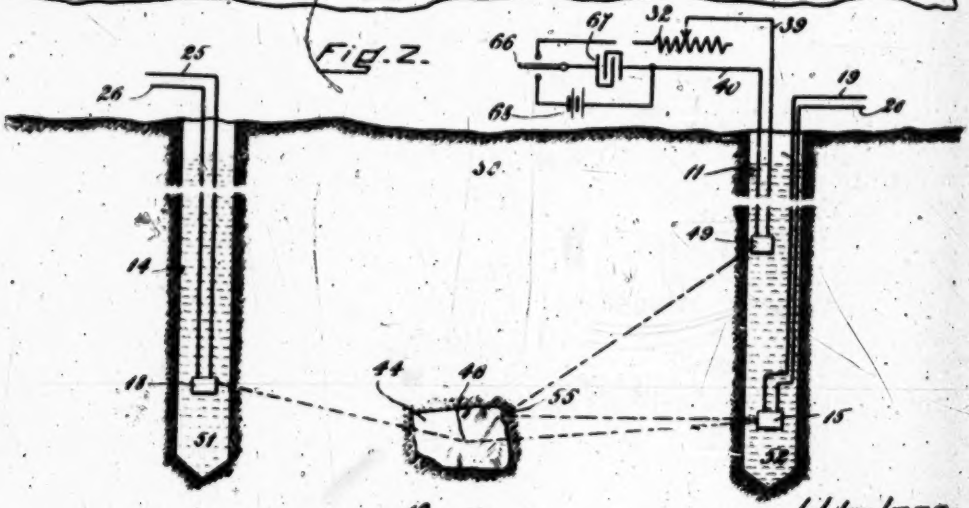


Fig. 3.



INVENTOR:
Reginald A. Fessenden
By Cotton & Hayes
HIS ATTORNEYS.

UNITED STATES PATENT OFFICE.

REGINALD A. FESSENDEN, OF BROOKLINE, MASSACHUSETTS, ASSIGNOR TO SUBMARINE SIGNAL COMPANY, OF WATERVILLE, MAINE, A CORPORATION OF MAINE.

METHOD AND APPARATUS FOR LOCATING ORE-BODIES.

1,240,328. Specification of Letters Patent. Patented Sept. 18, 1917.

Original application filed April 2, 1914, Serial No. 828,972. Divided and this application filed January 15, 1917. Serial No. 142,421.

To all whom it may concern:

Be it known that I, REGINALD A. FESSENDEN, of Brookline, in the county of Norfolk and State of Massachusetts, a citizen of the United States, have invented a new and useful Improvement in Methods and Apparatus for Locating Ore-Bodies; of which the following is a specification.

This application is a division of my United States application Serial No. 828,972 filed April 2, 1914.

The invention described herein relates to methods and apparatus whereby, being given or having ascertained, two or more of the following quantities, *i. e.*, time, distance, intensity and medium, one or more of the remaining quantities may be determined.

For example, being given the distance between two points in a mine, and having determined the time taken by a sound wave to travel between the two points, it is possible to draw conclusions in regard to the probable nature of the rock between the two points, or if an echo be observed, or a refraction of the sound, it is possible to estimate the distance of the reflecting or refracting vein.

Heretofore only such ore bodies have been discovered as have had an edge of the mineral vein extending to the surface of the earth and not covered by debris to such an extent as to be hidden, or such as have been reached by drill holes sunk at random in locations where minerals were suspected. The ore bodies so discovered must form an extremely small fraction of the total of such bodies and it is the object of the present invention to disclose methods and apparatus for discovering such hidden ore bodies by means of measurements made on the velocity, direction, reflection, refraction, absorption and other phenomena, of sounds transmitted through the medium containing the ore bodies, *i. e.*, the earth.

By the method herein described I have been able to detect and determine the location of a body of mineral, invisible to the eye, at a distance of two and a half miles, and farther, the test being witnessed and verified by a number of skilled engineers.

In the drawings accompanying and forming a part of this specification,

Figure 1 is a diagrammatic plan, and

Fig. 2 an illustrative section showing also a different source of energy.

Fig. 3 is a modification of the receiver, these views being in part diagrammatical and showing apparatus and methods suitable for carrying out my invention.

In Figs. 1 and 2, 50 represents a territory, which may be assumed to have an area of 25 square miles, within which it is desired to determine the presence or absence of mineral veins.

Four drill holes, 11, 12, 13, 14, shown in plan in Fig. 1 and two of them in section in Fig. 2, are first drilled at the four corners of the territory, approximately five miles apart, and of a depth sufficient to secure the desired results. These holes are filled with water 51, 52, Fig. 2. Sound detective devices, 15, 16, 17, 18, such as microphones or preferably small oscillators, as described in United States Patent No. 1,167,366, January 4, 1916, are suspended in these holes below the water line.

These sound receiving devices are connected by the pairs of leads, 19, 20, 21, 22, 23, 24, 25, 26, to the secondaries 31, 33, 35, 37, of transformers, as shown, and to oscillographs of the usual photographic recording type, but preferably with the galvanometer elements of the quartz fiber, described by applicant at the American Association for the Advancement of Science, 1894, and commonly known as Einthoven galvanometers.

49 is a sound producing apparatus, preferably of the said oscillator type, connected by its leads, 39, 40, to the primaries 32, 34, 36, 38, of the transformers in the oscillograph circuits, and to the alternating current dynamo 42, when the key 41 is depressed. 43, 44 are ore bodies.

The primaries 32, 34, 36 and 38 of the transformers are adjustable with reference to the secondaries, as shown, and are so adjusted that when the key 41 is depressed a moderately strong indication is produced on the photographic records of the oscillographs 27, 28, 29, 30, which fixes on the photographic records the instant at which the key is depressed, and at the same time a sound is sent out from the oscillator 49, which after being reflected as at 45 by the ore body 43, or reflected back as from 55, Fig. 2, by the ore body 44, or reflected as from 46 by the ore body 44, or refracted as at 47, 48 by the ore body 44, or proceeding directly through the earth, as shown by the dotted lines 56, 57, reaches the indicators 17, 18, 16,

15, and is recorded on the oscillographs 29, 30, 28, 27.

Since the oscillograph photographic strip moves with a regular and known velocity, determined in the manner well known in the art, the distance on the strips between the records produced through the transformers when the key 41 was pressed down, and the records made by the sounds received whether direct, or by reflection or refraction or by the echo, will indicate the distance between the drill holes and the ore bodies.

For example, if the distance between the record made on the oscillograph 30 by the transformer 37, 38 on depressing the key 41, and the record made by the arrival of the sound directly along the line 59 (which would be easily identified, being the first sound to record itself after the depression of the key), is five inches, then one inch on the record corresponds to one mile in distance, since 11 is five miles from 14. This establishes the standard of measurement on the oscillograph.

If, then, the length between the key depression record and the record made at 30 by the sound reflected at 46 is 9 inches, it is evident that the sound proceeding out from 49 and reflected at 46 and finally reaching 14, has traveled 9 miles. If, again, the length between the key depression record on the oscillograph 27 and the record made by the sound sent out from 49 and reflected back from 55, Fig. 2, is eight inches, then it follows that the ore body 44 is approximately 4 miles from the point 11. The ore body therefore lies at the intersection of the sphere described about 49 with radius 4 miles, with the sphere described about 18 with radius 9 minus 4, *i. e.*, 5 miles.

The exact point on the line of intersection may be found in a number of ways. For example:

1. By placing 49 in the drill holes 12 or 13 or 14 and taking other sets of records another line of intersections may be found. The point of intersection of the two lines of intersection will give the point at which the ore body is, or sufficiently close thereto.

2. By determining, by means of the apparatus of applicant's United States application Serial No. 54,556, filed October 7, 1915, shown diagrammatically in Fig. 3, and referred to below, the exact direction of the reflection points 46 of Fig. 1 and 55 of Fig. 2, thus knowing the directions and the distances obtained as given above, the ore body is located.

3. By drilling a test hole, passing near but on the far side of the line of intersection obtained as above,

Other modifications of applicant's method may be used. In fact, the mere determination of the time elapsing between the key depression record and the echo record made by reflection at 55, Fig. 2, together with a determination of the direction from which the echo is received is sufficient.

The extent of the ore body can be obtained by readings made by transferring 49 to the drill holes 12, 13, 14, and taking readings on the oscillographs on sending out sounds at these drill holes; or it may be determined by the refraction of the sound sent out from 49 and received at 16, or by the echo obtained at 16 when the sounder 49 is operated at the drill hole 12.

In place of using an alternator 42, a condenser discharge may be used to actuate the sounder 49, as shown in Fig. 2. Here the condenser key 66, on being depressed, charges the condenser 67 from the battery 68 and on the key being released and coming up against the top key contact, discharges the condenser through the transformer secondary 32 and sounder 49, thus making a single sound impulse, or a rapidly oscillating one, if the discharge is an oscillatory one.

The vertical angle of reflection may be determined by hauling the transmitter 49 or the receivers 18, 15, up or down in the drill holes.

In Fig. 3 is shown the apparatus for determining the direction of the sound received. Here 15, 15′, are two sound receivers, preferably small oscillators, connected in series preferably, their leads being the conductors 19, 20, connected to the oscillograph 27,

53 is a rod supporting the two receivers, 15, 15′, by which they may be turned in any direction. On turning them, the sound will be a maximum if they are connected so as to assist each other, when they are in a plane at right angles to the direction of the received sound. If they are connected so as to oppose each other, the sound will be a minimum when they are in this plane. In this way by drawing a perpendicular to the plane so determined, the direction from which the sound comes may be determined.

By the term "sound inflection" I mean bending of the line of sound propagation, either by reflection, or by refraction.

What I claim is:

1. That method of determining the location of ore bodies which consists in generating sound waves and observing their inflection.

2. That method of determining the location of ore bodies by generating sounds and observing their inflection by the ore bodies, and their velocities.

REGINALD A. FESSENDEN.

DEFENDANT'S EXHIBIT 0-5

Tucker Patent No. 1,351,356

[Endorsed]: Filed Nov. 4, 1942.

1078

W. S. TUCKER.

SOUND DETECTING DEVICE.

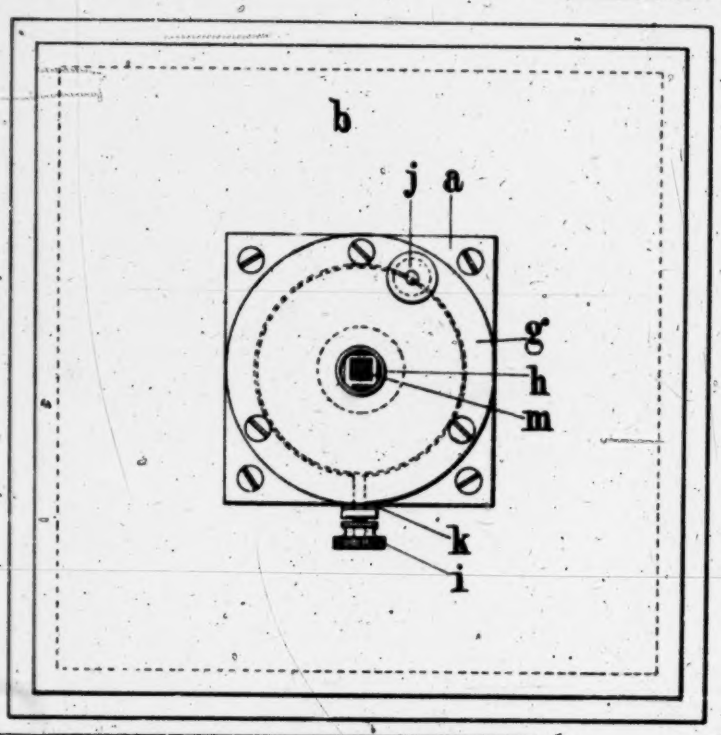
APPLICATION FILED JAN. 9, 1919.

1,351,356.

Patented Aug. 31, 1920.

4 SHEETS—SHEET 1.

Fig.1.



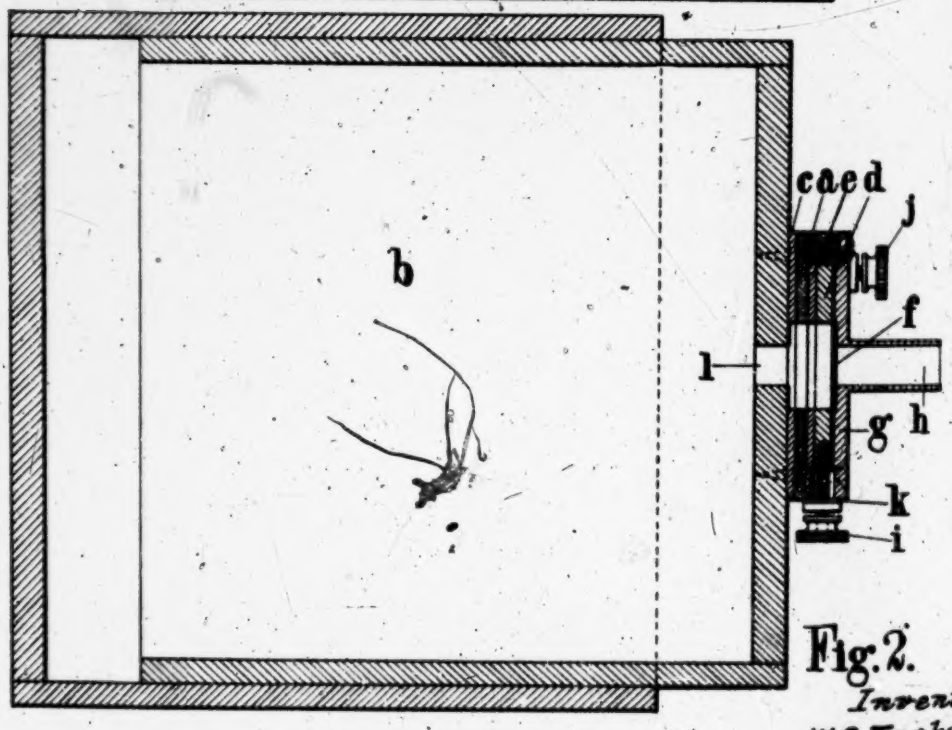


Fig.2.

Inventor
W.S. Tucker
By A.R. Kerslake
Atty

1075

W. S. TUCKER.
SOUND DETECTING DEVICE.
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Patented Aug. 31, 1920.
4 SHEETS—SHEET 2.

Fig.3.

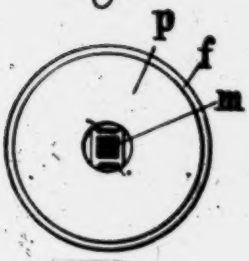


Fig.4.

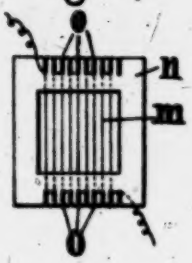
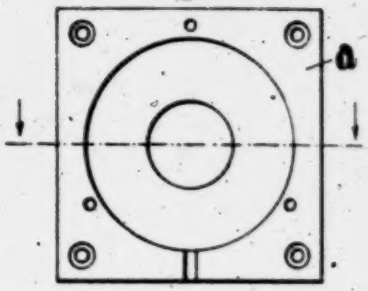


Fig.7.



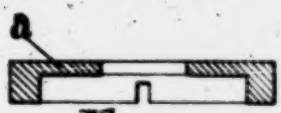


Fig.8.

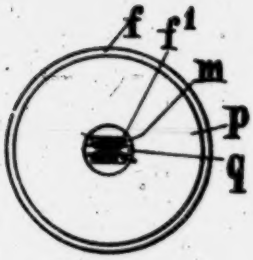


Fig.5.



Fig.6.

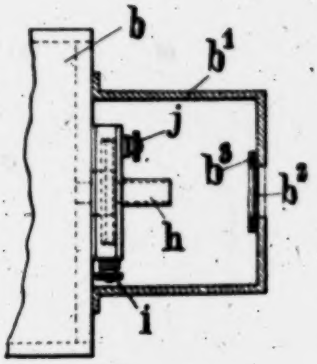


Fig.11.



Fig.9.

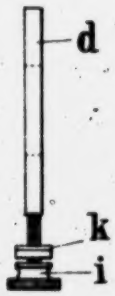


Fig.10.

Inventor
W. S. Tucker
By H. R. Kerslake
Atty

1080

W. S. TUCKER.

SOUND DETECTING DEVICE.

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4 SHEETS—SHEET 3.

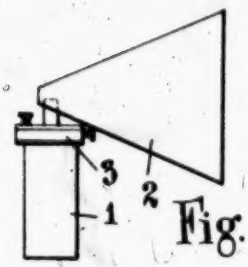


Fig.12.

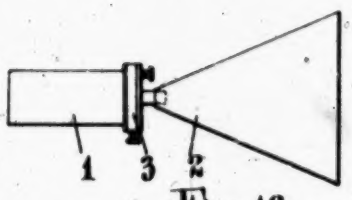


Fig.13.

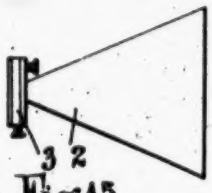


Fig.15.

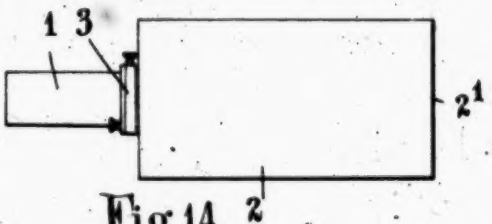


Fig.14.

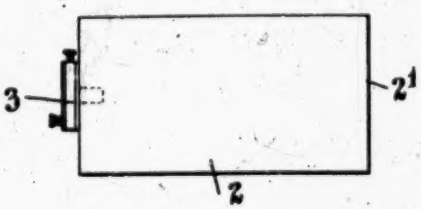


Fig.16.

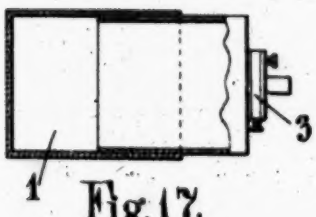


Fig.17.

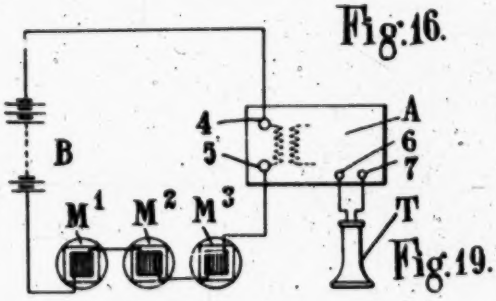


Fig.19.



Fig.18.

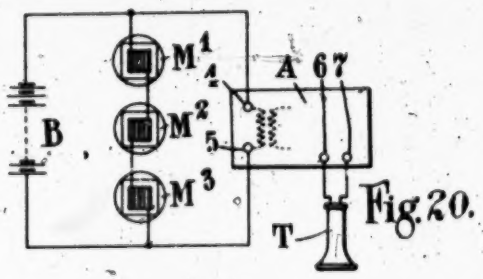


Fig.20.

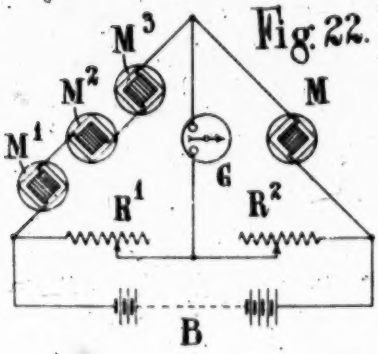


Fig.22.

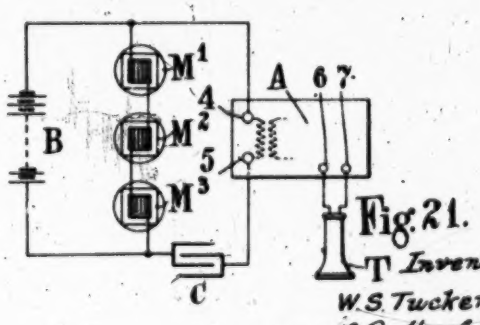


Fig.21.

Inventor
W. S. Tucker
By H. R. Kerslake
Atty

1082

W. S. TUCKER.
SOUND DETECTING DEVICE.
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4 SHEETS—SHEET 4.

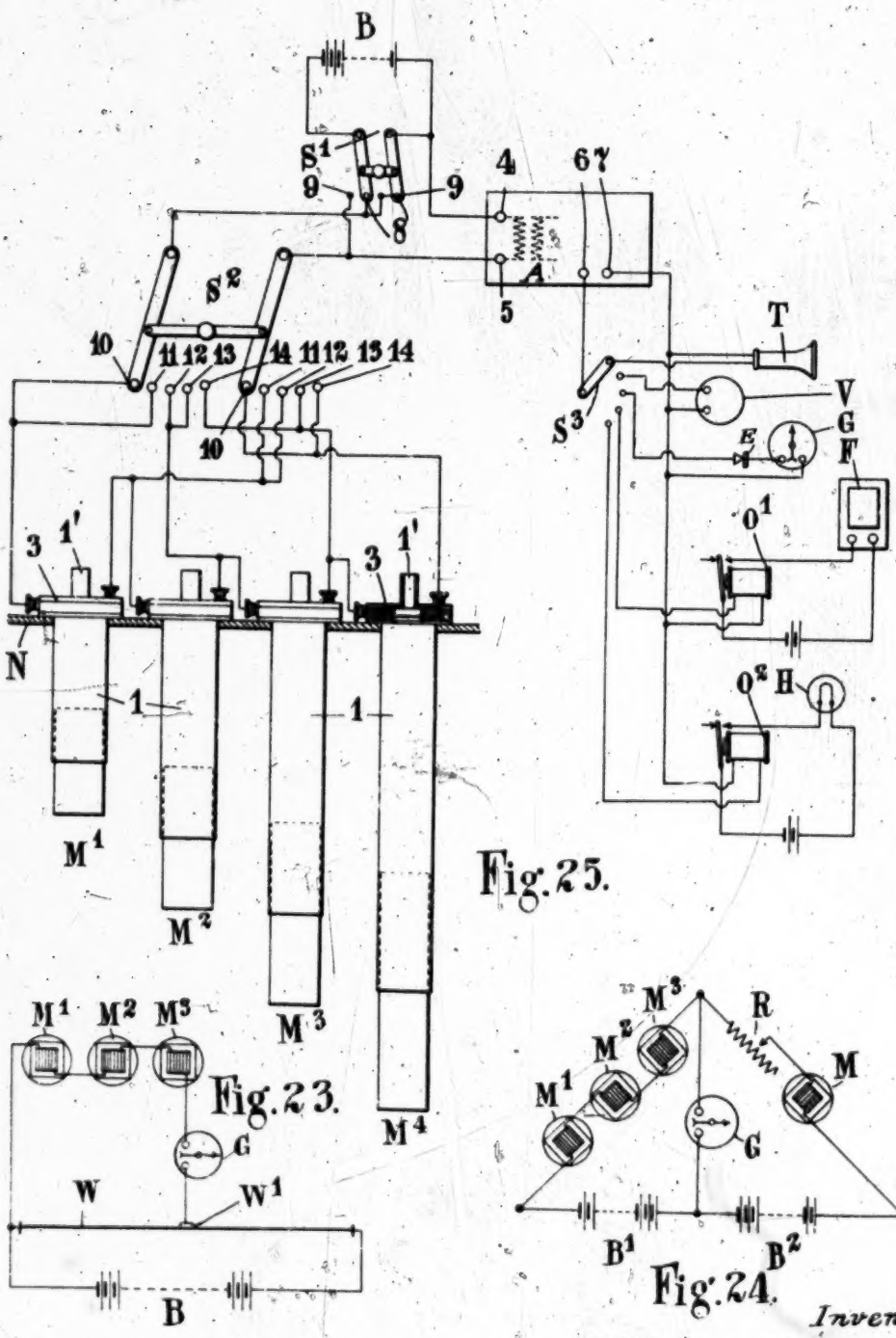


Fig. 25.

Fig. 23.

Fig. 24.

Inventor
W. S. Tucker
By H. R. Kerslake
Atty

UNITED STATES PATENT OFFICE.

WILLIAM SANSOME TUCKER, OF THAMES DITTON, ENGLAND.

SOUND-DETECTING DEVICE.

Specification of Letters Patent. Patented Aug. 31, 1920.

1,351,356.

Application filed January 6, 1919. Serial No. 269,902.

To all whom it may concern:

Be it known that I, WILLIAM SANSOME TUCKER, a subject of the King of Great Britain and Ireland, and residing at Imber Court, Experimental Ground, Thames Ditton, in the county of Surrey, England, have invented certain new and useful Improvements in and Relating to Sound-Detecting Devices, of which the following is a specification.

This invention relates to an improved thermic sound detecting device intended more particularly for determining the position of the origin of a sound produced by the discharge of a gun, although the use of the improved sound detecting device is not limited to such determination or origin, the invention being applicable also to the detection and measurement of such sounds and also to sounds emanating from other origins than from a gun, and being generally useful also for other purposes such as for the measurement of velocity and consequently of the quantity of gases or liquids flowing through tubes or pipes.

Various difficulties have hitherto been encountered with the ordinary type of microphone when used for the purpose hereinbefore more particularly referred to, viz., in conjunction with a sound ranging apparatus for determining the position of a gun. The ordinary type of microphone is more sensitive with regard to sound waves produced by the shell traveling through the air than with regard to those of the actual discharge of the gun and consequently the position of the gun as obtained by means of such a microphone is not accurate and has to be corrected by calculation.

One object of the invention is to provide an improved sound detecting device which responds more readily to the gun report and which overcomes the drawback of having to resort to calculation for obtaining the true position of the gun, other advantages obtained by the use of the sound detecting device constructed according to the present invention being that:—Both gun and sound waves produced by the shell traveling through the air are recorded; a characteristic record is obtained for each sound so that the records produced by the same gun can easily be distinguished from each other and with sufficient experience it can even be ascertained what type of gun has been fired; the sensitiveness of the sound detecting device is constant, and the same does not respond to ordinary noises, nor is it affected by vibration, and it assumes its normal condition immediately after each vibration.

According to the present invention use is made of an electrically heated thin conductor in combination with a sound box and with means for producing a small blast of air past said conductor into the sound box by the effect of the sound or gun wave which it is desired to detect, measure, or record, such detection, measurement, or record being obtained by the variation in the resistance of said electrically heated conductor produced by the cooling effect of the blast upon the conductor.

According to one mode of carrying the invention hereinbefore referred to into effect, a very thin platinum or other suitable wire is mounted close to, preferably in front of or within a small opening which may be made of any desired shape and is provided in the side of a wooden or other box. The wire which may be supported in a suitable frame is connected to terminals and an electric current is passed through it for the purpose of raising its temperature above that of the surrounding air, the temperature of the wire being reduced by the cooling effect of the small blast of air thereon, which is caused by the sound to be determined or recorded.

In all heated conductors having a positive temperature co-efficient the electrical resistance will be reduced by the small blast of air and this variation will depend entirely upon the intensity of the wave and its period will remain constant. It will thus be seen that the record of each sound will show a characteristic wave form determined by the variation in the electrical resistance of the heated conductor.

The variation in the electrical resistance of the heated conductor may be detected and measured by means of an Einthoven string galvanometer or other suitable instrument and permanent records of gun waves or sounds in general may be obtained by means of photographic or other recording devices.

The electrical connections between the sound detecting device and the various detecting, measuring or recording devices may be effected in any suitable manner, either directly or through the intermediary of a suitable coupling, for instance through a

transformer, the latter arrangement being especially useful when it is desired to use the sound detecting device as an automatic transmitter arranged some distance away from the recording instruments.

One mode of carrying the invention hereinbefore referred to into effect is illustrated, by way of example, in Figures 1–11 of the accompanying drawings.

Figs. 1 and 2 are a plan view and a sectional elevation of the improved sound detecting device respectively.

Fig. 3 is a plan view of the support on which the frame carrying the thin conductor is mounted.

Fig. 4 is a plan view of the frame carrying the thin conductor.

Fig. 5 is a plan view of a modified form of construction of the support carrying the frame on which the thin conductor is mounted, while

Fig. 6 is a perspective view of the frame shown in Fig. 5;

Figs. 7 and 8 are a plan view and a sectional elevation of one detail respectively, and

Figs. 9 and 10 are a plan view and a sectional elevation of another detail respectively, while

Fig. 11 illustrates a sub-aqueous sound detecting device.

Figs. 12 to 18 show largely diagrammatically different combined units of sound detecting device and acoustic resonator.

Figs. 19 to 25 illustrate various electrical connections.

Referring to the drawings, Figs. 1 and 2, *a* is a recessed frame of insulating material which is attached to the box *b*, preferably through the interposition of a sheet of india rubber *c*; *d* is a metal disk which is mounted within the frame *a*, preferably through the interposition of an india rubber washer *e*; *f* is a support carrying the frame on which the thin conductor is mounted, as hereinafter more particularly referred to in connection with Figs. 3, 4, 5 and 6; *g* is another metal disk which is attached to the frame *a* and is provided with a tubular extension *h* through which the blast is produced; *i* and *j* are contact terminals which are provided on the metal disks *d* and *g* respectively, and *k* is an insulating washer. The india rubber sheet *c*, the frame *a*, the india rubber washer *e*, the metal disk *d*, the support *f* and the metal disk *g* are provided with central holes to allow the passage of a current of air through the tubular extension *h* provided on the metal disk *g* and past the thin conductor, supported in or closely in front of, or behind the hole of the supporting disk *f*, into the box *b*, through a hole *l* provided in the latter.

Referring to Figs. 3 and 4, the thin conductor *m* is preferably made of Wollaston wire, the silver coated platinum being wound on a small open mica frame *n* preferably formed with teeth *o*, so that the thin conductor may conveniently be wound in a close zig-zag manner, as shown, all the windings lying in one and the same plane. The frame *n* with the thin conductor wound thereon is stuck on or is otherwise attached to the support *f*, which consists of a thin disk of mica provided on each side with an electrode *p* preferably consisting of a thin disk of silver stuck on or otherwise attached to the mica disk *f*, the arrangement being such that the thin conductor *m* lies within or closely in front of, or behind the central hole in the disk *f*. The two ends of the thin conductor *m* are soldered on to the two silver electrodes respectively.

The silver coating on that part of the Wollaston wire which lies in the opening of the frame and is intended to be exposed to the current of air is removed, by first coating the whole of the support *f* with exception of the part of the wire from which the silver is to be removed, with a layer of wax and then dipping the support into nitric acid.

According to the modification illustrated in Figs. 5 and 6, the thin conductor *m* is mounted in a zig-zag manner as shown between two strips or thin bars of insulating material attached to each other and forming a cross bar *q* which is stuck on or is otherwise attached to the mica disk *f* across the opening *f*¹ provided therein, so that the conductor *m* shall lie within or closely in front of or behind the opening in the mica disk. The two ends of the conductor *m* are connected to the two silver electrodes *p* as in the arrangement described with reference to Figs. 4 and 5.

In both forms of construction hereinbefore described, the electrical connection of the thin conductor with the other parts of the circuit or circuits is effected through the two silver electrodes *p* which are in metallic contact with the metal disks *d* and *g* provided with the contact terminals *i* and *j* respectively.

The box *b* on which the sound detecting device hereinbefore described is attached may be formed of two parts which are mounted telescopically, as shown in Figs. 1 and 2, in order to vary the capacity of the box and thereby obtain a resonant effect.

The sound detecting device may also be used as a device for detecting sounds propagated through water, in which case an auxiliary box *b*¹ (see Fig. 11) may be attached to the side of the box *b* carrying the sound detecting device, said auxiliary box being provided, preferably on the side facing the small opening and tubular extension *h* through which the blast is produced, with

a suitable diaphragm b^2 held in position by a ring b^3, by means of which diaphragm any vibrations imparted to the latter from the outside of the box will cause corresponding movements in the air blast past the heated conductor.

The electrical connections between the sound detecting device and the various detecting or equivalent devices are illustrated in connection with the second part of the invention hereinafter referred to.

According to a further feature of the present invention, use is made of a plurality of sound detecting devices, and more particularly of thermic sound detecting devices, each of which is combined with an acoustic resonator of a particular pitch in such a manner that a series of combined sound detecting device and acoustic resonators are obtained, the pitch of which extends along the whole range of acoustic vibrations, or along a portion of such range, according to the object in view.

The arrangement of sound detecting devices having the feature just referred to is more particularly useful in connection with the detection of sound, such as produced by aeroplanes, submarines, or other sources of sound; I wish it, however, to be understood that the invention is not limited to the detection of sound, as it may otherwise conveniently be used, *e. g.*, for the transmission of sound. This part of the invention is diagrammatically illustrated in Figs. 12 to 25.

Referring to Figs. 12 to 16, each combined unit of sound detecting device and acoustic resonator may comprise an open or closed tubular resonator 1 in open communication with a trumpet, or open box 2, with the open end at 2^1, and a thermic sound detecting device 3 inserted between the two, (see Figs. 12, 13 and 14), or a trumpet, or open box 2 with the open end at 2^1 in combination with the sound detecting device 3, the tubular resonator 1 being dispensed with. (See Figs. 15 and 16.)

The tuning of each combined unit of sound detecting device and acoustic resonator to a particular pitch may be either fixed or adjustable; in either case the tuning being attained in a well known manner by the proper adjustment of the shape, length, and volume of the resonating chamber, or of the aperture near the grid of the thermic sound detecting device, or otherwise. Fig. 17 illustrates the method of tuning wherein the volume of the resonating chamber 1 is varied by a telescopic sliding movement, and Fig. 18 the method of tuning wherein the volume of the aperture near the grid of the thermic sound detecting device 3 is varied by a screwing movement, of the tubular extension 1′ within a correspondingly screw-threaded member 1″.

The electrical connection between the thermic sound detecting devices and the other part of the electrical apparatus may be effected in various ways.

In the arrangement illustrated in Fig. 19, the various sound detecting devices M^1, M^2, M^3 are connected in series with each other and with the battery B and the input terminals 4, 5 of the primary of the first stage transformer associated with an amplifier A, the output terminals 6, 7 of which are connected to a telephone T or equivalent device.

The arrangements illustrated in Figs. 20 and 21 differ from that shown in Fig. 19 by the sound detecting devices M^1, M^2, M^3 being arranged in parallel with the battery B and the input terminals 4, 5 of the amplifier; in the case of Fig. 21, a condenser C of suitable capacity is inserted in series with the terminals 4, 5.

Referring to Fig. 22, illustrating a Wheatstone bridge arrangement, M^1, M^2 M^3 are the active sound detecting devices under the influence of the sound which is to be detected, M is a balancing sound detecting device which is not under the influence of the said sound, R^1, R^2 are two adjustable resistances, G is a galvanometer and B the battery.

The Wheatstone bridge arrangement may also be used for discriminating between two sounds of different pitch. In this case the balancing sound detecting device may be rendered operative for a sound outside the range of M^1, M^2, M^3, thus indicating a high pitch aeroplane, as against a lower pitch one, which renders the sound detecting device M^1 operative, the deflections being to the right or to the left, according as to whether the sound comes from the one or the other aeroplane.

Referring to Fig. 23 illustrating the potentiometer method M^1, M^2, M^3 are the sound detecting devices, B the battery, W a wire resistance and G a galvanometer, one end of which is connected to a sliding contact W^1.

Fig. 24 illustrates a compensating arrangement, in which M^1, M^2, M^3 are the active sound detecting devices, M a balancing sound detecting device which is not under the influence of the sound to be detected, R a variable resistance, G a galvanometer and B^1, B^2 two batteries.

Referring to the complete arrangement illustrated in Fig. 25, M^1, M^2, M^3, M^4 are a plurality of combined units of sound detecting device and acoustic resonator, each comprising an open or closed tubular resonator 1 of adjustable length, and a thermic sound detecting device 3 provided with a tubular extension 1′, as hereinbefore described. All these combined units, the number of which may be very large, are mounted on a suitable support N, each one of them being adjusted

to a particular pitch, in order to obtain a range of acoustic vibrations which shall be as wide as possible. The electrical terminals of the various sound detecting devices are connected in series with one another, the two end terminals of the series of sound detecting devices being connected through the intermediary of two switches S^1, S^2, to the battery B and the input terminals 4, 5 of an amplifier A, the output terminals 6, 7 of which are adapted to be connected by means of a switch S^3 to any one of a plurality of indicating or recording devices, viz., a telephone T, a vibration galvanometer V, a rectifying wave detector E associated with a direct reading galvanometer G, and through relays O^1, O^2, to an electric bell F, or lamp H, it being understood that any other indicating or recording device may be used instead.

When the switch S^1 is in the position in which it makes contact with the contacts 8, 8, while switch S^2 is in the position shown in the figure, the sound detecting devices are connected in series with the battery a. with the input terminals 4, 5 of the amplifier, and when it is shifted to the position in which it makes contact with the contacts 9, 9 while switch S^2 remains in the same position, the end terminals of the whole series of sound detecting devices are connected in parallel with the battery and the input terminals 4, 5 of the amplifier. When the switch S^2 is in the position indicated in the figure, in which it makes contact with the contacts 10, 10, all the sound detecting devices are inserted in series with each other in the input circuit of the amplifier. However, by shifting this switch so that it shall make contact with the contacts 11, 11—12, 12—13, 13— and 14, 14, while switch S^1 makes contact with 9, 9, only one of the sound detecting devices is inserted in the input circuit of the amplifier, viz., the sound detecting device M^1, M^2, M^3 or M^4, respectively.

It will thus be seen that when all the sound detecting devices are connected in series with each other, the arrangement will allow of an automatic detection of very faint acoustic vibrations owing to the fact that at least one of the sound detecting devices, namely, that one which happens to be in tune with the vibrations produced by the source of sound will respond to the acoustic vibrations, thereby causing the sound to be detected. Further, if it is desired to concentrate the attention upon a sound having a particular pitch, the sound detecting device unit tuned to such pitch may be connected to the amplifier with the exclusion of all the other sound detecting devices, by means of the switch S^3.

It will also be seen that the sensitiveness of the apparatus will also be increased owing to the fact that in the case of simultaneous acoustic vibrations emanating from the source of sound, several sound detecting devices will simultaneously respond to the different vibrations of respective frequencies, thereby causing an increased variation in the electric circuit.

I wish it to be understood that the mode of carrying the invention into effect and the various details hereinbefore referred to may be modified without in any way departing from the spirit of the invention.

What I claim is:—

1. A sound detecting device comprising an electrically heated thin conductor in combination with a sound box and with means for producing a small blast of air past the electrically heated thin conductor into the sound box, the said conductor being arranged between the said means and the sound box, as and for the purpose set forth.

2. A sound detecting device comprising an electrically heated thin conductor in combination with a sound box having a small opening and with means for producing a small blast of air past the electrically heated thin conductor and small opening into the sound box, the said conductor being arranged between the said means and the said small opening, as and for the purpose set forth.

3. A sound detecting device comprising an electrically heated thin conductor in combination with a sound box having a small opening and with a tubular member through which the blast is produced, the said conductor being arranged between the said small opening and tubular member, as and for the purpose set forth.

4. A sound detecting device comprising in combination an electrically heated thin conductor, a support of insulating material for the said conductor, an opening in the said support across which the said conductor is arranged to lie, a sound box having a small opening, and means for producing a small blast of air past said conductor into the sound box, the said support being arranged with its opening between the small opening in the box and the said means, as and for the purpose set forth.

5. A sound detecting device comprising in combination an electrically heated thin conductor, a support of insulating material for the said conductor, an opening in the said support across which the said conductor is arranged to lie, two thin metal disks attached to the latter support, an opening in each of the thin metal disks facing the opening in the said support, the two ends of the thin conductor being electrically connected to the two thin metal disks respectively, a sound box having a small opening, and means for producing a small blast of air past said conductor into the sound box,

the said support being arranged with its opening between the small opening in the box and the said means, as and for the purpose set forth.

6. A sound detecting device comprising in combination an electrically heated thin conductor, an open frame of insulating material, teeth on the said frame for the reception of the thin conductor, and means for producing a small blast of air past said conductor into the sound box, as and for the purpose set forth.

7. A sound detecting device comprising in combination an electrically heated thin conductor, a support of insulating material for the said conductor, an opening in the said support, two thin metal disks attached to the latter support, an opening in each of the thin metal disks facing the opening in the said support, the two ends of the thin conductor being electrically connected to the two thin metal disks respectively, two metal plates in metallic contact with the two thin metal disks respectively, openings in the metal plates opposite the opening in the support of insulating material, a sound box, and means for producing a small blast of air past the thin conductor into the sound box, as set forth.

8. A sound detecting device comprising in combination an electrically heated thin conductor, a support of insulating material for the said conductor, an opening in the said support, two thin metal disks attached to the two ends of the thin conductor being electrically connected to the two thin metal disks respectively, two metal plates in metallic contact with the two thin metal disks respectively, openings in the metal plates opposite the opening in the support of insulating material, contact terminals on the two metal plates, a sound box and means for producing a small blast of air past the thin conductor into the sound box, as set forth.

9. A sound detecting device comprising in combination an electrically heated thin conductor, a support of insulating material for the said conductor, an opening in the said support, two thin metal disks attached to the latter support, an opening in each of the thin metal disks facing the opening in the said support, the two ends of the thin conductor being electrically connected to the two thin metal disks respectively, two metal plates in metallic contact with the two thin metal disks respectively, openings in the metal plates opposite the opening in the support of insulating material, a tubular member on one of the metal plates in communication with the opening therein, and a sound box, as set forth.

10. A sound detecting device comprising a sound box, a small opening in the latter, a frame attached to the sound box, a small opening in the said frame, an electrically heated thin conductor, a support of insulating material for the said conductor, an opening in the said support, two thin metal disks attached to the latter support, an opening in each of the thin metal disks facing the opening in the said support, the two ends of the thin conductor being electrically connected to the two thin metal disks respectively, two metal plates in metallic contact with the two thin metal disks respectively, and openings in the metal plates opposite the opening in the support of insulating material, the latter support with the thin conductor thereon and with the two metal disks attached thereto, together with the metal plates, being mounted on the frame attached to the sound box, as set forth.

11. A sound detecting device comprising an electrically heated thin conductor in combination with a sound box having a small opening, the volume of which sound box is capable of being varied, and with means for producing a small blast of air past the electrically heated thin conductor into the sound box, the said conductor being arranged between the said means and the said small opening, as and for the purpose set forth.

12. In combination a plurality of differently tuned sound detecting devices, each sound detecting device comprising an electrically heated thin conductor, a sound box having a small opening, and means for producing a small blast of air past the electrically thin heated conductor into the sound box, the said conductor being arranged between the said means and the said small opening, and the plurality of sound boxes being capable of being adjusted so as to have different volumes, thereby constituting a series of open resonators of different pitch as and for the purposes set forth.

In testimony whereof I have signed my name to this specification.

WILLIAM SANSOME TUCKER.

1089 To 1094.

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DEFENDANT'S EXHIBIT O-7

Williams Patent No. 1,671,262

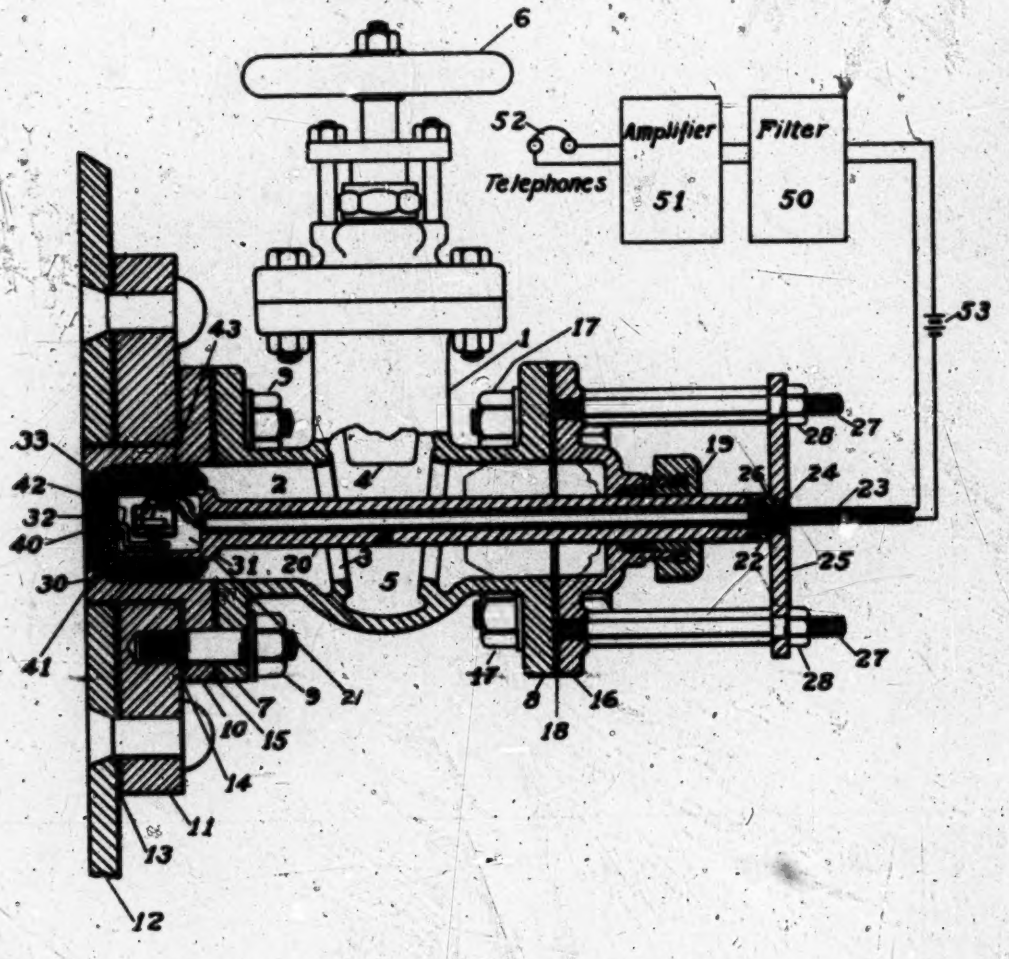
[Endorsed]: Filed Nov. 4, 1942.

May 29, 1928. 1,671,262

R. L. WILLIAMS

SUBMARINE SOUND RECEPTION

Filed April 2, 1925



INVENTOR.
ROBERT L. WILLIAMS
BY Ezekiel Wolf
ATTORNEY.

Patented May 29, 1928.

1,671,262

UNITED STATES PATENT OFFICE.

ROBERT LONGFELLOW WILLIAMS, OF NEWTON, MASSACHUSETTS, ASSIGNOR TO SUBMARINE SIGNAL CORPORATION, OF BOSTON, MASSACHUSETTS, A CORPORATION OF DELAWARE.

SUBMARINE SOUND RECEPTION.

Application filed April 2, 1925. Serial No. 20,227.

The present invention relates to an improvement in submarine sound reception and comprises mainly a skin mounted aperiodic receiver in a special valve within a ship and conveying the signals received to a listener through a circuit designed for selective reception.

One of the objects of the present invention is to present a suitable removable mounting and removable aperiodic receiver which can be changed without the necessity of the ship going into dry dock.

Another feature of the present invention is to surround the actuated diaphragm of the receiver by such an inertia mass that the vibrations of the ship will have little effect upon exciting the diaphragm or the microphone connected therewith.

A further feature of the present invention is the combination of an aperiodic receiver with a filter and amplifying circuit which presents distinct advantages in the selective reception of submarine sound waves.

Other features of the present invention will be learned from the description in the specification and the drawing in which the figure shows a part sectional view of the receiver and the circuit used for reception.

The receiver is, of course, installed under the water line of the vessel where the diaphragm will be continually adjacent to the water.

In the figure, 1 indicates the valve proper which consists of a hollow cylinder 2, with a gate opening 3, behind which the plunger 4 is adapted to move into a seat 5 to close the rear of the cylinder from the outer water. This is accomplished by turning the hand wheel 6. Both ends of the gate valve are provided with flanges 7 and 8.

The front flange 7 is bolted to a composition seat 10 by means of machine screws 9, 9, which pass through the latter and thread into a heavy inertia ring 11 rigidly riveted to the ship's plate 12. Between the ship's plate and inertia ring is a suitable gasket 13, and likewise the composition seat 10 and the flange 7 are provided with suitable gaskets 14 and 15, the former between pieces 10 and 11, and the latter between pieces 7 and 10.

The rear end of the cylinder 2 is closed in the following manner. A cap 16 is firmly clamped to the flange 8 by bolts 17, 17. Between 8 and 16 is a suitable gasket 18. A stuffing box 19 of usual construction closes the opening in the cap 16, through which the stem 20 passes.

At one end of the stem 20 is the receiving apparatus 21 which will be described shortly. At the opposite end of the stem 20 is a cap 22, forming part of a clamping means to hold the cable 23 in position so that no strain will be placed upon the wires within the stem 20. The cap 22 is threaded at 24 to receive the piece 25 which normally bears against a shoulder 26 of the cap 22. Near the edge of the piece 25 are studs 27, 27 and nuts 28, 28 threading thereon, the studs 27 threading into the piece 16 and the nuts 28 serving to hold the piece 25 firmly against the shoulder 26 of the stem 20. In this way the receiver 43 is held firmly in place.

The receiver 21 consists of a rubber shell 30 having an opening in the back and a recess 31. The front is formed of a diaphragm 32 with a beveled edge 33 which through the pressure exerted by the piece 25 upon the stem 20 rests firmly in the bevel of the piece 10. Moulded in the rubber diaphragm 32 is a stud 40 with a threaded end 41 capable of receiving the rod 42 holding the microphone receiver 43, which can be attached to the former.

Two wires of the microphone receiver pass to the cable 23 within the stem 20. The cable 23 leads to a filter circuit 50, which transmits the signal to an amplifying circuit 51 and then to the telephone receivers 52. The battery 53 is shown in the microphone circuit.

The operation of the apparatus is obvious and therefore needs little explanation. The incoming signal vibrating the diaphragm causes a change of resistance in the microphone in the usual manner which is transmitted to the filter and finally heard in the telephone.

In particular the rubber diaphragm is practically aperiodic so that it is equally sensitive to all frequencies. As the result of this the low frequency water noises actuate the diaphragm at their own frequency. This

is not true of a highly tuned diaphragm. In the latter case the low frequency noises, which are apt to be of greater intensity than the incoming signal, actuate the tuned diaphragm by impact excitation. In this case the water noises are already transformed in frequency to that of the signal which, of course, is tuned to the natural frequency of the diaphragm, when actuating the microphone. In such a case a filter would pass through the noises if it passed through the signal, and would therefore be of no purpose at all. The aim of the present system is to preserve the characteristic frequencies of the incoming disturbances and filter the bands in which these frequencies occur so that only the incoming signal is transmitted to the amplifying circuit. In this manner all opportunity of the incoming disturbing noises operating the amplifier by impact excitation is also avoided. The present system while sensitive to very weak noises and signals is practically free from disturbances of the former, after the signals have been filtered and amplified.

In addition to this feature the ship's noises are practically entirely excluded by the loose coupling effected between the microphone and the ship's plate. This is effected by means of the large inertia plate 11, which is rigidly riveted to the skin of the vessel, by the composition seat 10 and by the rubber shell 30, which only sets snugly but not rigidly in the composition seat. The mass of the diaphragm which is exceedingly small being made of the rubber which is of low specific gravity is only loosely connected with a very large inertia mass of iron of high specific gravity, the combination of which may be shown both mathematically and experimentally to be of the very loosest coupling. The result is, therefore, that very little of the ship's vibrations is transmitted to the diaphragm and these therefore are entirely excluded from the system. This is especially advantageous since the vibrations, due to the ship's noises, may be of almost any frequency, depending upon the kinds of apparatus used upon the ship.

In addition the composition seat serves another function. As it will not corrode and is only bolted to the inertia plate, it can easily be removed when the ship is in dry dock. This is an advantage over former systems used.

In describing the microphone receiver 43 above, it should have been remarked that the present installation is adapted to be installed in the bottom of the vessel. In this position the button itself, that is the plane of the electrodes, will be vertical so that the granular carbon which lies loose between the electrodes can come in contact with both electrodes and make a good electrical circuit. The installation is such that whatever position the diaphragm 32 is in, the microphone is in a vertical position. This is accomplished by bending the stem 42 in such a manner that the button is always vertical.

Having now described and explained the features of my invention, I claim:

1. In combination a vessel having an opening in its skin, a soft rubber shell having a diaphragm wall with a plane outer portion and a peripheral seat, a microphone, means mounting said microphone on said diaphragm wall and means mounting said shell in said opening in the skin with the outer diaphragm wall flush with the outer skin surface, including a large inertia member about said opening and a portion having a seat cooperating with said shell seat.

2. In combination a vessel having an opening in its skin, a soft rubber shell having a diaphragm wall with a plane outer portion and a peripheral seat, a microphone, means mounting said microphone on said diaphragm wall and means mounting said shell in said opening in the skin with the outer diaphragm wall flush with the outer skin surface, including a large inertia member permanently secured to the skin surrounding said opening and a seat member bolted to said inertia member in which said shell rests.

3. In combination a vessel having an opening in its skin, a soft rubber shell having a diaphragm wall with a plane outer portion and a peripheral seat, a microphone, means mounting said microphone on said diaphragm wall and means mounting said shell in said opening in the skin with the outer diaphragm wall flush with the outer skin surface including an inertia member in which said shell sets secured to the skin and means for maintaining said shell firmly in said inertia member.

4. In combination a vessel having an opening in its skin, a soft rubber shell having a diaphragm wall with a plane outer portion and a peripheral seat, a microphone, means mounting said microphone on said diaphragm wall and means mounting said shell in said opening in the skin with the outer diaphragm wall flush with the outer skin surface including an inertia member surrounding said opening and a removable seat member bolted to said inertia member in which said shell rests.

5. In combination a vessel having an opening in its skin, a soft rubber shell having a diaphragm exposed to the outer water adjacent to said opening, a microphone, means mounting said microphone on said diaphragm and means mounting said shell in said opening in the skin with the outer diaphragm wall flush with the outer skin surface, including a large inertia member about said opening and a portion having a seat cooperating with said shell seat.

6. In combination a vessel having an opening in its skin, a soft rubber shell having a part formed as an aperiodic diaphragm exposed to the outer water adjacent to said opening, a microphone, means mounting said microphone on said diaphragm and means mounting said shell in said opening in the skin with the outer diaphragm wall flush with the outer skin surface, including a large inertia member about said opening and a portion having a seat cooperating with said shell seat.

In testimony whereof I affix my signature.

ROBERT LONGFELLOW WILLIAMS.

DEFENDANT'S EXHIBIT O-9

Taylor Patent No. 1,847,636

[Endorsed]: Filed Nov. 4, 1942.

1096

March 1, 1932. J. B. TAYLOR 1,847,636

VIBRATION RECORDING AND REPRODUCING APPARATUS

Filed Nov. 28, 1927

Fig. 1.

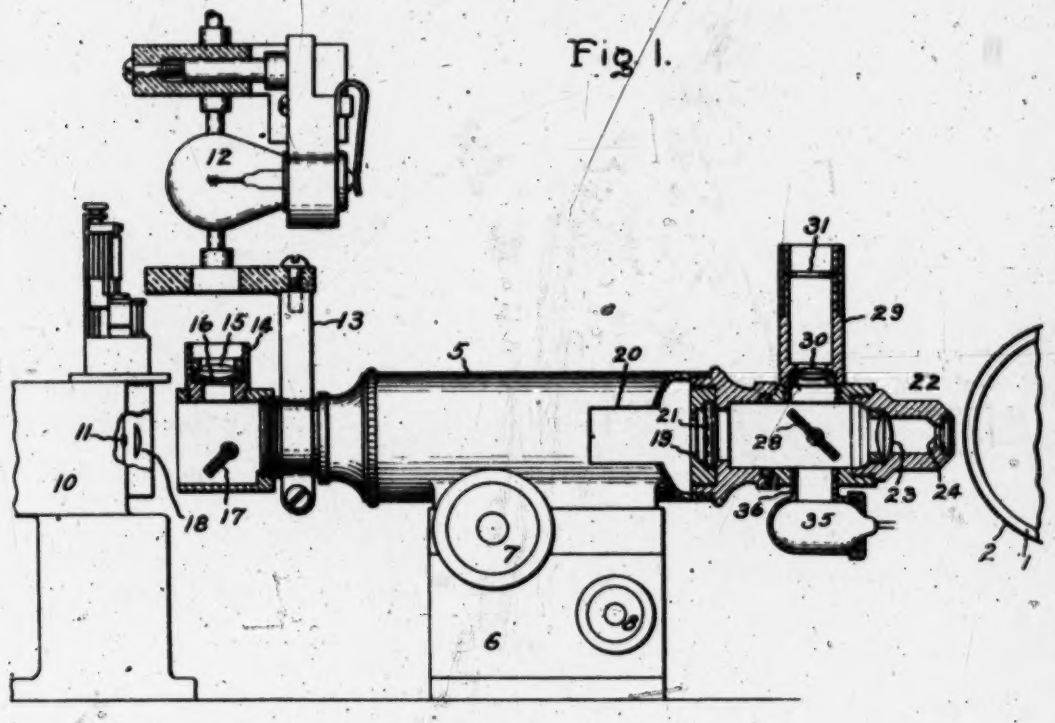
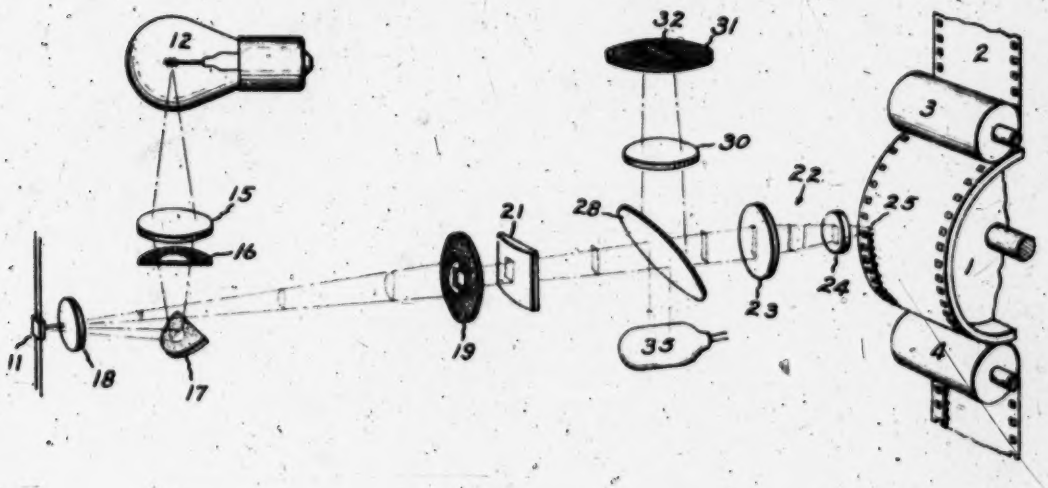


Fig. 2.



Inventor
John B. Taylor,
by Alexander Sinclair
His Attorney.

Patented Mar. 1, 1932

1,847,636

UNITED STATES PATENT OFFICE

JOHN B. TAYLOR, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK

VIBRATION RECORDING AND REPRODUCING APPARATUS

Application filed November 28, 1927. Serial No. 236,045.

My invention relates to apparatus for photographically recording vibrations on a light sensitive member and to apparatus for reproducing vibrations from a record thereof. My invention relates particularly to apparatus for making the photographic record in the form of a band on a moving film by means of a beam of light which is caused to vary in accordance with the vibrations to be recorded.

For the faithful recording of vibrations having relatively high frequencies, such for example as are represented by the overtones in certain sound waves, and for the true reproduction of such vibrations previously recorded, for example, on a film it has been found that with moderate film speeds the light beam employed in either case must be extremely narrow where it engages the film. In apparatus heretofore constructed, a beam having the necessary narrowness usually has been obtained by the use of a screen having an aperture therein of the order of one mil in width arranged close to the moving film. Arrangements also have been proposed wherein a screen displaced from the film and having a larger aperture is used and by the use of suitable lenses a reduced image of the aperture is formed on the film. With such forms of apparatus I have found it difficult in certain cases to obtain sufficient light intensity on the film and where an aperture of microscopic width is used close to the film many other difficulties are met with in the construction and the operation of the apparatus. It is an object of my invention, therefore, to provide improved apparatus of this character which shall avoid difficulties experienced in the construction and use of former apparatus, shall be efficient and shall include means which facilitate the adjustment and use of the apparatus.

In accordance with one feature of my invention I dispense with the use of narrow apertures either arranged close to the moving light sensitive member or at a distance therefrom and employ optical means for bending the rays from a suitable light source to form a line of light on the light sensitive member having the desired intensity and the desired narrow width.

My invention will be better understood from the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

Referring to the drawings, Fig. 1 is a side elevation, partly in section, of apparatus involving my invention and Fig. 2 shows the optical system of the apparatus.

Certain features of my invention relate to apparatus for making a photographic record on a moving light sensitive member while other features relate both to such apparatus and to apparatus for reproducting vibrations previously recorded. In the drawings illustrating my invention, I have shown apparatus for recording electrical vibrations on a moving film by means of an oscillograph galvanometer. This apparatus is of the type wherein by optical means a line of light is focused on the film as distinguished from the type employing a mechanical slit or light aperture arranged close to the moving film. On the drawings I have shown the film supported on the face of a rotatable drum. Such a drum I have shown at 1, the film 2 as seen in Fig. 2, passing between the drum and the idlers 3 and 4. Tube 5 carrying the main portion of the optical system is adjustably mounted on the base 6 whereby it may be given the various movements necessary to properly position the line of light on the film. I have shown only the adjusting screws 7 and 8 for effecting respectively the coarse and fine adjustment of the tube longitudinally. Adjacent the end of the tube 5 further from the film is the oscillograph galvanometer 10 having the small mirror 11 and having means for effecting various adjustments thereof. In use, the oscillograph galvanometer is electrically connected with a source of electrical vibrations to be recorded. If the apparatus is to be used to record sound, a sound pick-up device, such for example as a condenser microphone, may be connected to the oscillograph galvanometer preferably through a suitable amplifying device. The source of light comprising the incandescent lamp 12 is shown mounted on one end of tube 5 by means of the bracket 13, suitable adjustments being

provided for properly positioning the lamp. In the lateral branch 14 of tube 5 is the lens 15 and the diaphragm 16, the latter, as shown more clearly in Fig. 2, having a straight edge whereby a portion of the light beam from lens 15 is shut off. The purpose of the diaphragm is to give a sharp edge to that part of the light beam which finally reaches the film. Below the lens and diaphragm and offset from the center of the tube 5 is the adjustable mirror 17 set at approximately 45° so as to reflect the light beam to the oscillograph mirror 11. I have shown this mirror 17 semicircular in shape, this form being used for convenience in avoiding interference with the beam after reflection from the oscillograph mirror. I have also shown the lens 18 mounted immediately in front of the oscillograph mirror through which lens pass both the incident and the reflected beams. To facilitate the proper positioning of the beam of light reflected from the oscillograph mirror, I have shown the target 19 having a square opening therein mounted near the other end of the tube and for observing the position of the beam on the target a suitable opening 20 is provided in the wall of the tube. Adjustments are made to bring the straight side of the bright spot corresponding to the sharp edge of the beam approximately at the middle of the opening in the target. That portion of the beam which passes through the target first traverses the cylindrical lens 21 which is arranged with its axis vertical or at right angles to the vibratory movement of the beam. Beyond the cylindrical lens 21 is the lens system 22 shown as comprising lenses 23 and 24 which in cooperation with the cylindrical lens 21 arranged in the manner described refract the rectangular light beam passing the target into a beam which focused on the film, produces a very narrow bright line of light 25. The lens system 22 would focus the beam to a point-like spot on the film; the cylindrical lens 21 spreads the spot transversely of the film to a line of light. As the beam is vibrated in response to vibrations of the mirror 11, the length of the bright line 25 varies accordingly, the end of the line which moves being sharply defined whereby as the film advances with a steady movement it is exposed in a manner to form a serrated edge record thereon. For the lens system 22 I have found it convenient to employ a microscope objective, of suitable equivalent focus and numerical aperture, with which a bright line of the required length and having a width of 1 mil, more or less, is readily obtained.

For the purpose of better enabling the operator to focus and position the line of light on the film I have provided the apparatus with means for viewing a magnified image of the light line. In the present embodiment of my invention, I have shown within the tube 5 and between the cylindrical lens and the lens 23 a thin piece of glass 28, su as a piece of cover glass, arranged at angle approximately of 45° and opposite th glass in a branch tube 29 I have shown t lens 30 and the screen 31 which for examp may be a piece of ground glass. A certa small portion of the light reaching the fil in the light line 25 will be reflected from t film surface and a part of this reflected ligh after passing back through the lens system is partly reflected by the inclined glass through the lens 30 on the screen 31 whe it forms an enlarged image 32 of the ligh line 25 on the film.

Such an enlarged image of the light lin is of great assistance to the operator. enables him continuously to check and mai tain the proper focus and position of the ligh line during the process of recording and provides a constant visual indication of th deflection amplitude and of the film actio as for example the presence of film on th drum or the absence thereof due to runnin out of breakage. A reference line or line scratched or otherwise marked on the scree 31 facilitate the quick and accurate adjust ment of the apparatus to properly positio the light line on the film.

While I have illustrated my invention a comprising an arrangement for making a ser rated edge or variable width record it is no limited to the making of such records but i also adapted for making records of the con stant width variable density type. If such record is to be made the oscillograph galva nometer will be rotated 90° so as to assume horizontal position in the form illustrate and the diaphragm will be rotated 90° on th axis of the light beam passing therethrough With the construction illustrated it may b found more desirable to rotate the entire as sembly including the lamp 12, lens 15, dia phragm 16 and mirror 17 instead of the dia phragm only. This will rotate the beam reaching the target 19 through 90° and caus it to vibrate in a vertical plane, thereby vary ing the amount of light passing through th target to the film. The length of the ligh line 25 now remains constant but the bright ness of the line varies with the deflections o the oscillograph mirror whence the film is ex posed in a band of constant width and vari able intensity longitudinally.

For monitoring the recording operation particularly where sound is being recorde the operator may be provided, for example wth a head set connected in circuit with th oscillograph galvanometer or with the sound pick-up device. This, however, does not tak into account the operation of the oscillograph galvanometer and the optical system. I hav provided therefore a monitoring device com prising the photo-electric cell 35 arranged a the end of the lateral tube 36 opposite the tub

29 and the glass 28. Although most of the light beam which is vibrated by the oscillograph mirror and which passes through the target 19 will pass on through the glass 28 to the film a certain small proportion of it will be reflected laterally into the cell 35. By connecting the cell to the operator's telephone preferably through a suitable amplifying device he is able to supervise the operation of the entire apparatus by hearing and judging the intensity and quality of the musical or other sounds being recorded.

While I have shown and described my invention as comprising a recording apparatus, certain portions thereof, namely, the optical system including the cylindrical lens 21 and the lens system 22 and also the apparatus for viewing the light line, are also applicable for use in a reproducing apparatus. In the latter case it is understood that the light beam is not vibrated and a suitable photo-electric cell is arranged behind the film whereby the amount of light reaching the cell is controlled by the record on the film.

I have chosen the particular embodiment described above as illustrative of my invention and it will be apparent that various modifications may be made without departing from the spirit and scope of my invention which modifications I aim to cover by the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. Apparatus for recording vibrations on a moving light sensitive member comprising a source of light from which a beam is directed toward said member, means for vibrating said beam transversely of the movement of said member in accordance with the vibrations to be recorded, means in the path of said beam adapted to focus the beam to a point-like spot of light on the member and means for spreading the beam to form in cooperation with the focusing means a thin line of light on the member.

2. Apparatus for recording vibrations comprising a light sensitive member supported for longitudinal movement, a source of light, means responsive to said vibrations for vibrating a beam from said source transversely of the movement of said member, and means comprising a cylindrical lens having its axis at right agles to the direction of movement of the beam for bending the rays of the beam, to form a narrow transverse line of light on said film.

3. Apparatus for recording vibrations comprising a film supported for longitudinal movement, a source of light, means responsive to said vibrations for directing a beam from said source toward said film and for vibrating the beam transversely of said film movement, a cylindrical lens arranged in said beam having its axis extending in the direction of the movement of the film, and a reducing lens system between the film and the cylindrical lens.

4. Apparatus for recording vibrations comprising a light source, a mirror adapted to be vibrated in accordance with the vibrations to be recorded, means for directing a beam of light from said source on said mirror, a diaphragm arranged to give the beam a sharp edge at one side thereof, a film supported for longitudinal movement in a direction at right angles to the vibratory movement of the light beam reflected from said mirror, and means comprising a cylindrical lens having its axis extending in the direction of the film movement for bending the rays of said reflected light beam to form a narrow transverse line of light on the film.

5. Film sound recording apparatus comprising a light source, an oscillograph galvanometer having a mirror adapted to be vibrated in accordance with the sound waves to be recorded, a mirror for directing a light beam from the source to the oscillograph galvanometer mirror, a diaphragm arranged to give the beam a sharp edge at one side thereof, a lens arranged close to the oscillograph galvanometer mirror through which pass the incident and reflected beams, a film, a drum for supporting and moving the film longitudinally at right angles to the vibratory movement of the reflected beam, and means for refracting the rays of the reflected beam to form a narrow transverse line of light on the film, comprising a cylindrical lens having its axis at right angles to the direction of movement of the reflected beam and a microscope objective adjacent the film.

6. In apparatus for recording vibrations on a film or for reproducing vibrations from a film record, a movable film, means for projecting a beam of light toward the film, a lens system for producing a narrow line of light on the film traversed by said beam comprising a cylindrical lens having its axis at right angles to the said narrow line and a spherical lens, a reflecting member arranged in the beam between said lenses, and a viewing screen upon which an enlarged image of said line of light is reflected by said member.

7. In apparatus of the character described, a movable film, a source of light, and means for focusing light from the source in a narrow band on the film comprising a cylindrical lens having its axis at right angles to the band and a spherical lens between the film and the cylindrical lens.

8. Film sound recording apparatus comprising a film supported for longitudinal movement, means for projecting toward said film a beam of light variable in accordance with the sound to be recorded, a photo-electric device and means arranged in the path of said beam for partially reflecting it to said photo-electric device.

9. Film sound recording apparatus com-

prising a film supported for longitudinal movement, means for projecting a light beam toward said film, means for vibrating said beam in accordance with the sound to be recorded, a photo-electric cell arranged adjacent said beam, and a member arranged in said beam constructed partially to reflect the rays thereof into said cell.

10. A device for approximately uniform illumination of a slit-shaped field, containing a source of light, a cylindrical lens system of collective effect, whose cylindrical axis is perpendicular to the longitudinal axis of the slit-shaped field, and a spherical lens system of collective effect disposed behind the cylindrical system, the cylindrical system being adapted to project in the main section perpendicular to its cylinder axis, approximately in the entrance pupil of the spherical system, an image of the source of light, and the spherical system being adapted to alone project an image of the source of light approximately in the plane of the field to be illuminated.

11. A device for approximately uniform illumination of a slit-shaped field, containing a source of light, a cylindrical system of collective effect, whose cylindrical axis is perpendicular to the longitudinal axis of the slit-shaped field, and a spherical system of collective effect disposed behind the cylindrical system, the cylindrical system having a diameter allowing the passage of all those rays which are emanated from any point of the source of light to any point of the periphery of the entrance pupil of the spherical system, and being adapted to project in the main section perpendicular to its cylinder axis, approximately in the entrance pupil of the spherical system, an image of the source of light, which is at least as long as the diameter of the said entrance pupil, and the spherical system being adapted to alone project an image of the source of light approximately in the plane of the field to be illuminated.

12. Film sound recording apparatus comprising a film supported for longitudinal movement, means for projecting toward said film light variable in accordance with the sound to be recorded, a photoelectric device and means arranged in the path of said light for partially reflecting it to said photoelectric device.

13. In combination with an optical system for focusing a minute luminous image upon a film sound record, a cylindrical lens so positioned in relation to the remainder of the system as to spread the minute luminous image laterally of the sound record into a linear image.

In witness whereof, I have hereunto set my hand this 25th day of November, 1927.

JOHN B. TAYLOR.

PLAINTIFF'S EXHIBIT No. 18

Lehr & Wyatt Patent No. 2,047,974

[Endorsed]: Filed Nov. 4, 1942.

July 21, 1936. P. E. LEHR ET AL 2,047,974

METHOD AND APPARATUS FOR MEASURING WELL DEPTHS

Filed Nov. 1, 1933

Fig. 1

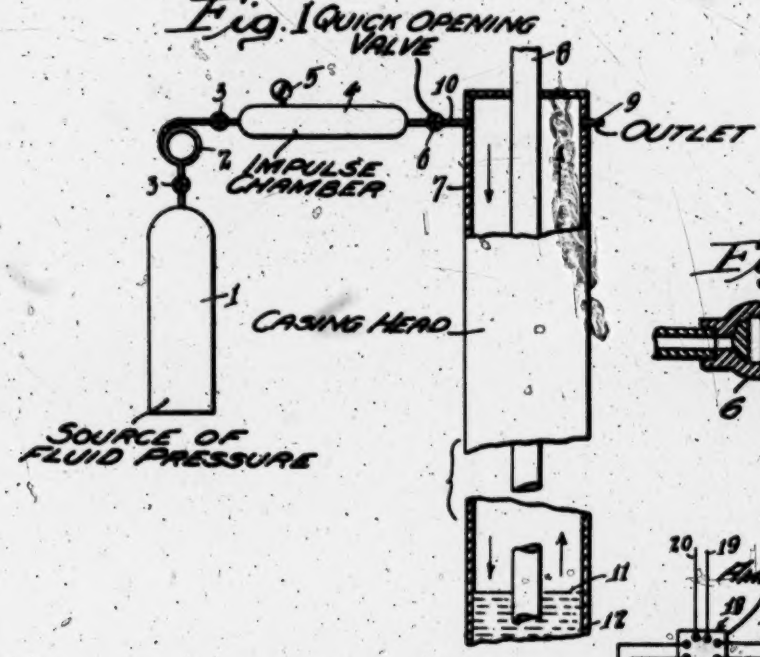


Fig. 4



Fig. 2

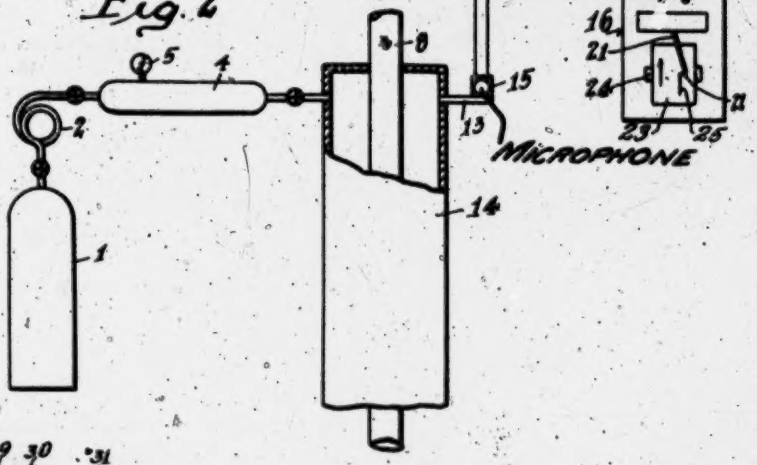
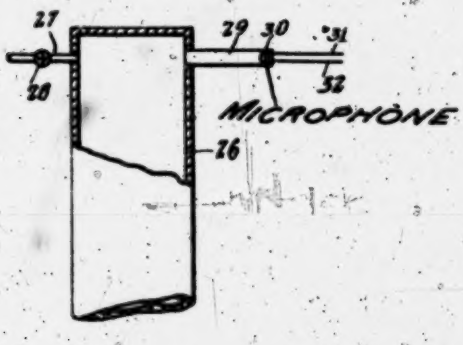


Fig. 3



Inventor

Harold S. Kyatt
Paul E. Lehr

By Lyon & Lyon

Attorneys

UNITED STATES PATENT OFFICE

2,047,974

METHOD AND APPARATUS FOR MEASURING WELL DEPTHS

Paul E. Lehr and Harold T. Wyatt,
Long Beach, Calif.

Application November 1, 1933, Serial No. 696,290

9 Claims. (Cl. 177—352)

This invention relates to a method and apparatus for measuring distances and while the invention may be employed for different specific purposes, it is intended to be used particularly for measuring the depth of deep wells.

The usual method of measuring a well depth is by means of a sand line or a similar line let down into the well. This consumes considerable time and labor.

It has been attempted to measure the depth of wells by using a sound wave method in accordance with which a sound is made at the mouth of the well and then the elapsed time is measured for this sound wave to pass to the bottom of the well and be reflected back to the mouth of the well. The sound wave method operates more perfectly in theory than in practice for the reason that there is really very little energy in a sound wave and in deep wells this energy becomes so dissipated that the recording of the elapsed time becomes difficult. In using the sound method referred to, perhaps the crookedness of the well hole has considerable to do with the dissipation of the energy of the sound, causing considerable reflection and partial absorption of the sound waves as they pass down the well and return.

The general object of this invention is to provide a simple method and simple apparatus for ascertaining the distance to a distant surface from a local point, and particularly the distance from a well head to the liquid surface at the bottom of the well. It is frequently desirable during operations to ascertain the depth of the well measured to the surface of the liquid at its bottom and it is also frequently necessary to have this information in connection with pumping wells. The present method and apparatus affords means for determining well depths without the use of a sand line, and saving considerable labor; and without the use of a "sound method" which is more or less unreliable.

The invention may be practiced to advantage in shut down fields where it is important that a systematic series of fluid level observations be taken in order to locate those wells where the casing has failed and allowed water to enter.

Further objects of the invention will appear hereinafter.

As regards the apparatus, the invention consists in the novel parts and combination of parts to be described hereinafter, all of which contribute to produce an efficient apparatus for measuring well depths.

As regards the method, the invention consists in those novel steps and combinations of steps to be described hereinafter, all of which contribute to produce an efficient method for measuring well depths.

A preferred embodiment of the invention is described in the following specification, while the broad scope of the invention is pointed out in the appended claims.

In the drawing:

Figure 1 is a diagrammatic view illustrating a simple form of apparatus which may be employed in practicing the invention. This view shows some of the apparatus in side elevation and shows a portion of a well casing partly in elevation and partly in section, with certain parts broken away;

Figure 2 is a view similar to Figure 1 but illustrating indicating or recording apparatus for producing a record of the elapsed time in making the test;

Figure 3 is a view similar to Figure 2 but illustrating simple apparatus for enabling the invention to be practiced where the well is under pressure;

Figure 4 is a longitudinal section through a quick opening valve or cock which may be of conventional type and which is employed in connection with the invention.

Before proceeding to a detail description of this invention, it should be stated that it employs the impulse wave principle, and the impulse wave is not generated by sound, but is generated by causing a sudden change in pressure at the well head. This change in pressure may be occasioned by a sudden liberation of a sufficient quantity of gas at the well mouth to cause a sudden substantial increase of pressure or a sudden decrease of static pressure within the well head, and it may be accomplished so that only a slight change in pressure at the local point results. In either case this produces a pressure impulse wave immediately at the well head; and the elapsed time is observed for this wave to traverse the space from the local point or well head, to an obstruction such as liquid in the well, and return to the well head. If the well is not under pressure, we prefer to employ a confined quantity of fluid, preferably gas, and suddenly liberate a small quantity of it into the well head.

If the well has considerable pressure in it, as frequently exists in gas wells, the invention can be practiced by allowing a quantity of gas at the well head to escape suddenly into the atmosphere. If this is done, an expansion wave immediately originates at the well head, passes down to the

surface of the liquid at the well bottom, and then travels up to the well head.

The elapsed time may be observed or indicated in any desired manner. If it is not desired to employ indicating instruments or recording instruments, a simple outlet can be provided at the well head, and a quantity of gas or air under pressure admitted suddenly into the well head, will, after a sufficient lapse of time, cause a perceptible puff of air or gas at the outlet. The elapsed time from the instant of admitting the gas or air under pressure until the occurrence of the puff at the outlet, will be the time consumed for the impulse wave to travel down and return from the bottom of the well. Such an impulse wave travels at the same velocity as sound, and if the elapsed time has been observed, it is possible, by employing a simple formula, to compute the depth of the well.

Referring more particularly to the parts and especially to Figure 1, 1 indicates a reservoir for any gas, for example, air, under considerable pressure, and this reservoir is connected through a suitable connection 2 with the valves 3, to an impulse chamber 4, being provided with a gauge 5 for indicating its internal pressure. The other end of this impulse chamber is connected through a quick opening valve or cock 6 to the well head or casing head 7. A flow pipe 8 may extend up through this casing head.

At any point on the periphery of the casing head an outlet 9 is provided to the atmosphere. The valve 6 may be mounted in a pipe connection 10 which can be readily connected to the side of the casing.

In using the apparatus, the valve 6 should be closed and the valves 3 opened to permit a quantity of the compressed air or gas to accumulate in the impulse chamber 4, for example, at a pressure of one hundred pounds per square inch. The valves 3 would then be closed.

In making the test for determining the well depth, the valve 6 would be suddenly opened, thereby permitting a quantity of the compressed air or gas in the chamber to flow into the well head. This will produce an impulse wave which would pass downwardly as indicated by the arrows at the left side of the casing and this wave would eventually impinge upon the surface 11 at the well bottom 12 and would be reflected back toward the head of the well. When the impulse wave, after its reflection by the surface 11, arrives at the well head, a perceptible puff of the air or gas will occur at the outlet 9. This puff can be felt readily simply by holding one's hand in front of the outlet. At the instant that the valve 6 is opened a stop watch is started, and at the instant that the puff is felt at the outlet 9, the stop watch is stopped. The elapsed time will be the time required for the impulse wave to traverse the space from the local point at the well head to the surface 11, and return.

The velocity of this impulse wave will be substantially the same as that of a sound wave and can be computed by the following formula:

$$\text{Velocity} = \sqrt{\frac{Cp}{Cv} \times \frac{P}{D}}$$

In this formula Cp equals the specific heat of the gas or air at constant pressure and Cv equals the specific heat of the gas or air at constant volume. The pressure P is usually expressed in pounds per square ft., and the density D of the gas would be expressed in pounds mass per cubic ft. This will express the velocity in feet per second.

From this formula it is evident that the velocity of the impulse wave is independent of the pressure, for the reason that when the pressure is increased the density is also increased in the same proportion. If very accurate results are necessary, correction for temperature changes may be made according to well-known formulas.

If it is desired to have the result of the test indicated or recorded, this can be accomplished by providing a small pipe connection 13 (see Figure 2) which is attached to the casing 14 instead of the outlet 9, and this connection may carry a microphone 15 which is electrically connected with an indicating or recording instrument 16. If desired, the circuit connection 17 between the microphone and the indicator or recorder 16 may include an amplifier 18 connected to conductors 19 and 20 of an electric power circuit.

The recorder 16 illustrated may be provided with a pen arm 21 which would be controlled by an impulse in the circuit 17, and this pen arm would carry a pen or pencil 22 to run on the face of a recording drum 23 mounted to rotate on its horizontal axis in bearings 24.

This recording drum would be rotated at a uniform speed when the test was started, and the pen 22 would run in a straight line 25 on the drum and produce a laterally disposed peak in the line when the test started, and when the test ended by the return of the impulse wave from the bottom of the well. The test would be made in the same manner as that described in connection with Figure 1, and the apparatus used would be the same as illustrated at the left side of Figure 2.

If the well is under pressure, the invention can be practiced without the use of a high pressure gas, by merely permitting the quick exit of some of the gas in the well. This is illustrated in Figure 3 in which 26 indicates the well head which is provided at one side with a connection 27 carrying a quick opening valve or cock 28. The casing is provided with a pipe connection 29 carrying a microphone 30 with circuit wires 31 and 32 connecting it up to an amplifier and recording instrument. In practicing the invention, as illustrated in Figure 3, the sudden exit of a small quantity of gas under pressure from the interior of the head will cause an impulse wave to start from the well head, and thence to the liquid at the bottom of the well; this impulse will return, and the instant of arrival of this impulse wave at the well head 26 will be indicated by the microphone. The microphone and its connected indicating and recording instrument would also indicate the instant at which the valve 28 was open, thereby indicating the elapsed time. Hence, in using the formula in this case, also, it will be necessary to bear in mind that the impulse wave travels twice through the length or depth of the well.

In using the term "gas" in this specification and claims, it should be understood that the term, when used in its broad sense, is intended to include air which is, in fact, a gas.

It is understood that the embodiment of the invention described herein, is only one of the many embodiments this invention may take, and we do not wish to be limited in the practice of the invention, nor in the claims, to the particular embodiment set forth.

It is evident that our invention can be practiced also when the casing has atmospheric pres-

sure within it or a partial vacuum, and with the same facility as when the well is under a high pressure.

What we claim is:—

1. A method of measuring the depth of a well having a casing head and casing, which consists in maintaining a confined supply of gas under pressure at the well head on the exterior of the casing, suddenly admitting a quantity of the said gas under pressure into the casing head and thereby producing a substantial change in static pressure and an impulse wave in the gas or air within the casing, and observing the elapsed time for the impulse wave to traverse the space from the casing head to the bottom of the well and back again to the casing head.

2. A method of measuring the depth of a well having a casing head and casing, which consists in confining a quantity of gas under pressure in the casing head, suddenly liberating a quantity of said gas and thereby suddenly reducing the static pressure in the casing head and producing an impulse wave in the gas within the casing, and observing the elapsed time for the impulse wave to traverse the space from the casing head to the well bottom and back to the casing head.

3. In apparatus for measuring the depth of a well, the combination of an impulse chamber carrying a gas maintained under pressure, a connection from the impulse chamber to the head of the well including a quick opening valve, said well having an outlet to the atmosphere, said parts cooperating so that when the valve is suddenly opened, a portion of the gas under pressure will pass into the well and thereby raise the static pressure of the gas at the head of the well to produce an impulse wave passing to the bottom of the well and reflected back to the head of the well, said impulse wave operating to produce a puff of gas at said outlet when the impulse wave arrives at the well head, thereby enabling the elapsed time during the wave's travel, to be observed.

4. In apparatus for measuring the depth of a well, the combination of an impulse chamber carrying a gas under pressure at the earth's surface, a connection from the impulse chamber to the head of the well including a quick opening valve, said well having an outlet to the atmosphere, said parts cooperating so that when the valve is suddenly opened, a portion of the gas under pressure will pass into the well and thereby cause an increase of static pressure in the gas in the well head, and produce an impulse wave passing to the bottom of the well and reflected back to the head of the well, and means for indicating the elapsed time for the wave to traverse the space to the well bottom and return.

5. In apparatus for measuring the depth of a closed well, the combination of an impulse chamber carrying a gas under pressure at the earth's surface, a connection from the impulse chamber to the head of the well including a quick opening valve, said parts cooperating so that when the valve is suddenly opened, a portion of the gas under pressure will pass into the well and thereby cause a rise in the static pressure in the well head, and produce an impulse wave passing to the bottom of the well and reflected back to the head of the well, and means connected with the well for indicating the elapsed time for the wave to traverse the space to the well bottom and return to the surface.

6. In apparatus for measuring the depth of a closed well, the combination of an impulse chamber carrying a gas under pressure, a connection from the impulse chamber to the interior of the well including a quick opening valve, said parts cooperating so that when the valve is suddenly opened, a portion of the gas under pressure will pass into the well and thereby cause a rise in the well head static pressure, and produce an impulse wave passing to the bottom of the well and reflected back to the head of the well, and a microphone connected with the well for indicating the instant the wave completes its travel within the well.

7. In apparatus for measuring the depth of a closed well, the combination of an impulse chamber carrying a gas under pressure, a connection from the impulse chamber to the interior of the well including a quick opening valve, said parts cooperating so that when the valve is suddenly opened, a portion of the gas under pressure will pass into the well and thereby raise the static pressure in the well head, and produce an impulse wave passing to the bottom of the well and reflected back to the head of the well, a microphone connected with the well, and a recording device electrically connected with the microphone.

8. In apparatus for measuring the depth of a closed well, the combination of an impulse chamber carrying a gas under pressure, a connection from the impulse chamber to the interior of the well including a quick opening valve, said parts cooperating so that when the valve is suddenly opened, a portion of the gas under pressure will pass into the well and thereby raise the static pressure in the well head, and produce an impulse wave passing to the bottom of the well and reflected back to the head of the well, a microphone connected with the well, an indicating device electrically connected with the microphone, and an amplifier between the microphone and the indicating device cooperating to indicate the elapsed time for the wave to traverse the space to the well bottom.

9. A method of measuring the distance to an obstruction or liquid in a well, which consists in maintaining a confined supply of gas under pressure at the well's mouth, suddenly liberating a quantity of the said gas under pressure at the well mouth and thereby producing a substantial change in static pressure and an impulse wave in the gas in the well, and observing the elapsed time for the impulse wave to traverse the space from the head of the well to the obstruction, and back again to the well's mouth.

HAROLD T. WYATT.
PAUL E. LEHR.

DEFENDANT'S EXHIBIT O-13

Scott Patent No. 2,173,426

[Endorsed]: Filed Nov. 4, 1942.

1108

Sept. 19, 1939. H. H. SCOTT 2,173,426

ELECTRIC SYSTEM

Filed Aug. 30, 1937 7 Sheets-Sheet 1

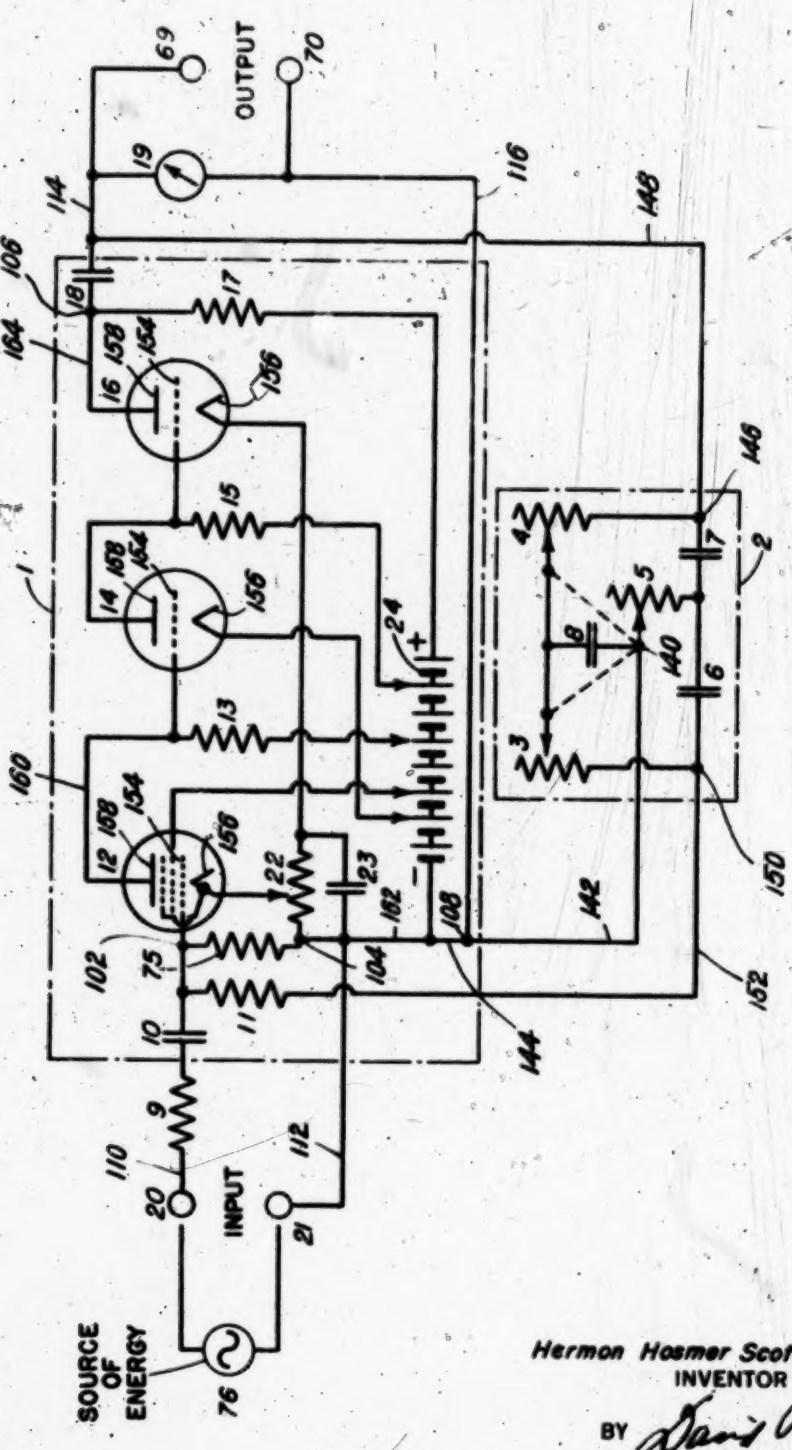


Fig.1

Hermon Hosmer Scott
INVENTOR

BY Davis Rines

ATTORNEY

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Sept. 19, 1939. H. H. SCOTT 2,173,426

ELECTRIC SYSTEM

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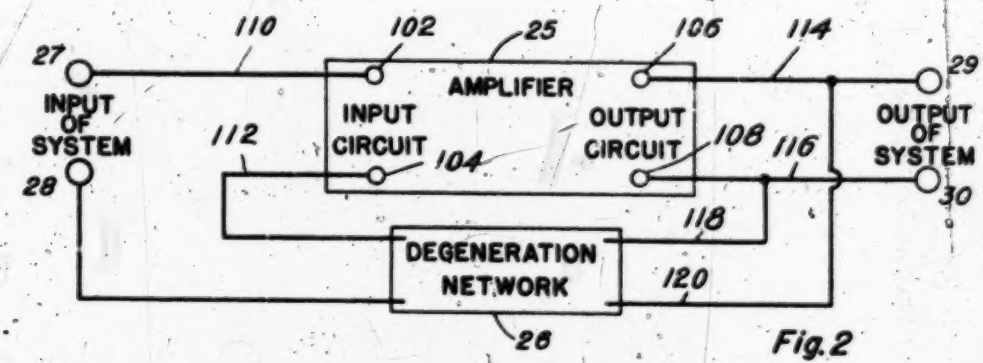


Fig. 2

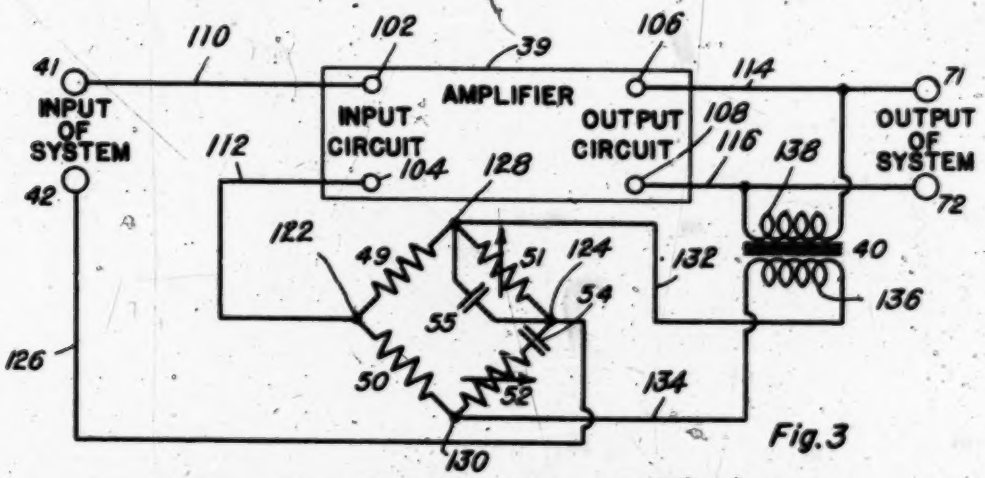


Fig. 3

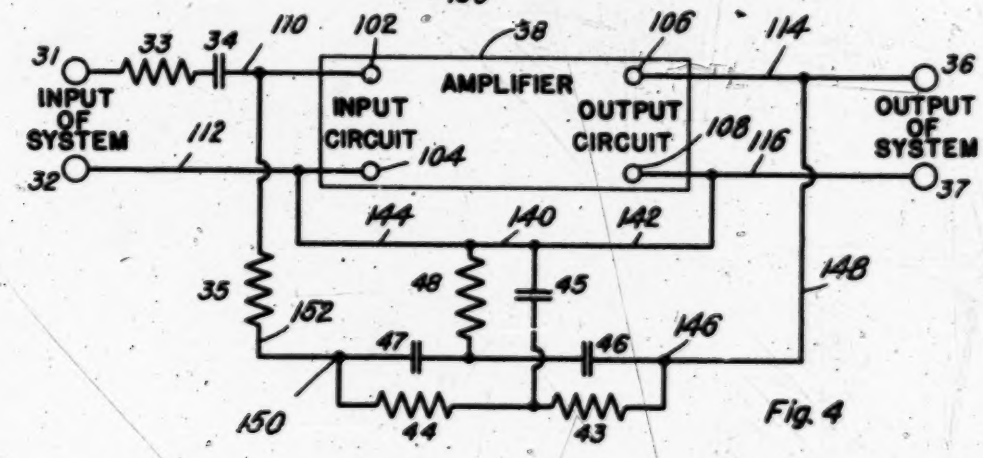


Fig. 4

Hermon Hosmer Scott
INVENTOR

BY David Rines

ATTORNEY

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Sept. 19, 1939. H. H. SCOTT 2,173,426

ELECTRIC SYSTEM

Filed Aug. 30, 1937 7 Sheets-Sheet 3

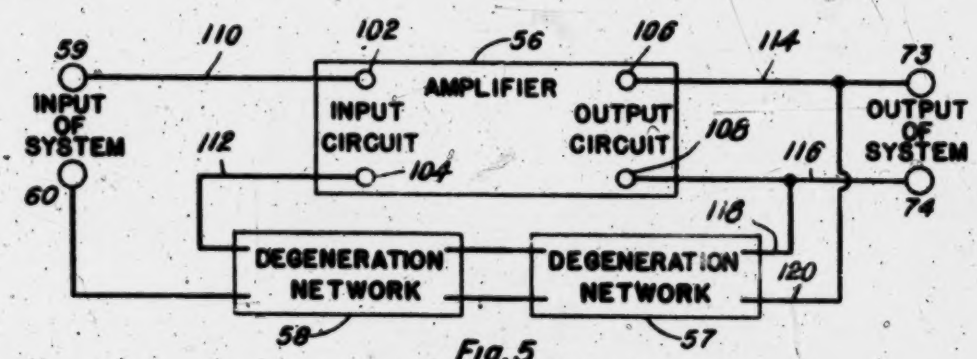


Fig. 5

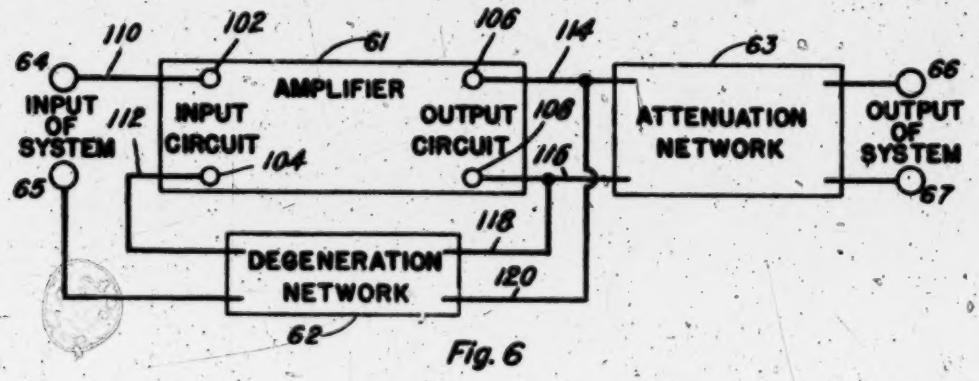


Fig. 6

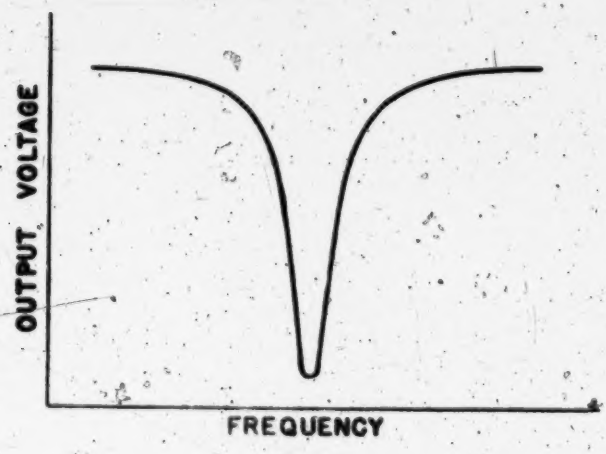


Fig. 7

Hermon Hosmer Scott
INVENTOR

BY David Rines

ATTORNEY

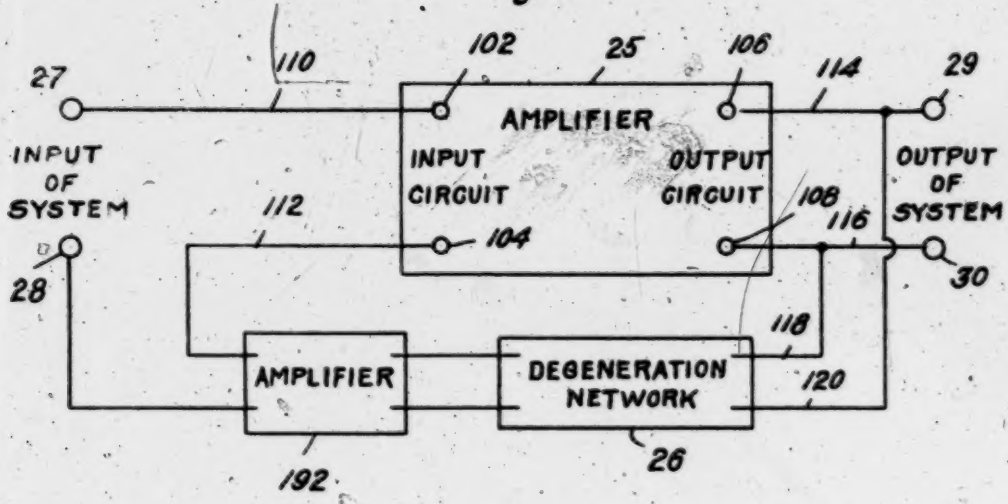
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Sept. 19, 1939. H. H. SCOTT 2,173,426

ELECTRIC SYSTEM

Filed Aug. 30, 1937 7 Sheets-Sheet 4

Fig. 13.



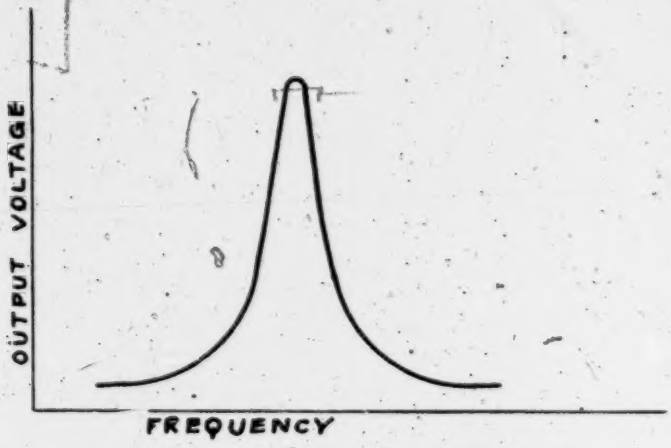


Fig. 8.

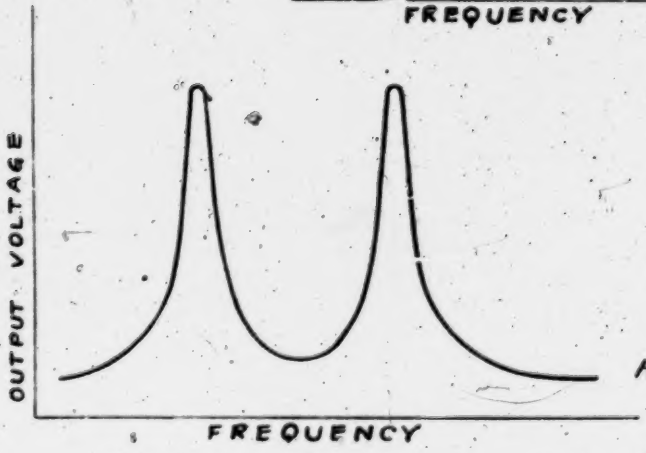


Fig. 9.

Hermon Hosmer Scott.
INVENTOR
BY David Rines
ATTORNEY

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Sept. 19, 1939. H. H. SCOTT 2,173,426

ELECTRIC SYSTEM

Filed Aug. 30, 1937 7 Sheets-Sheet 5

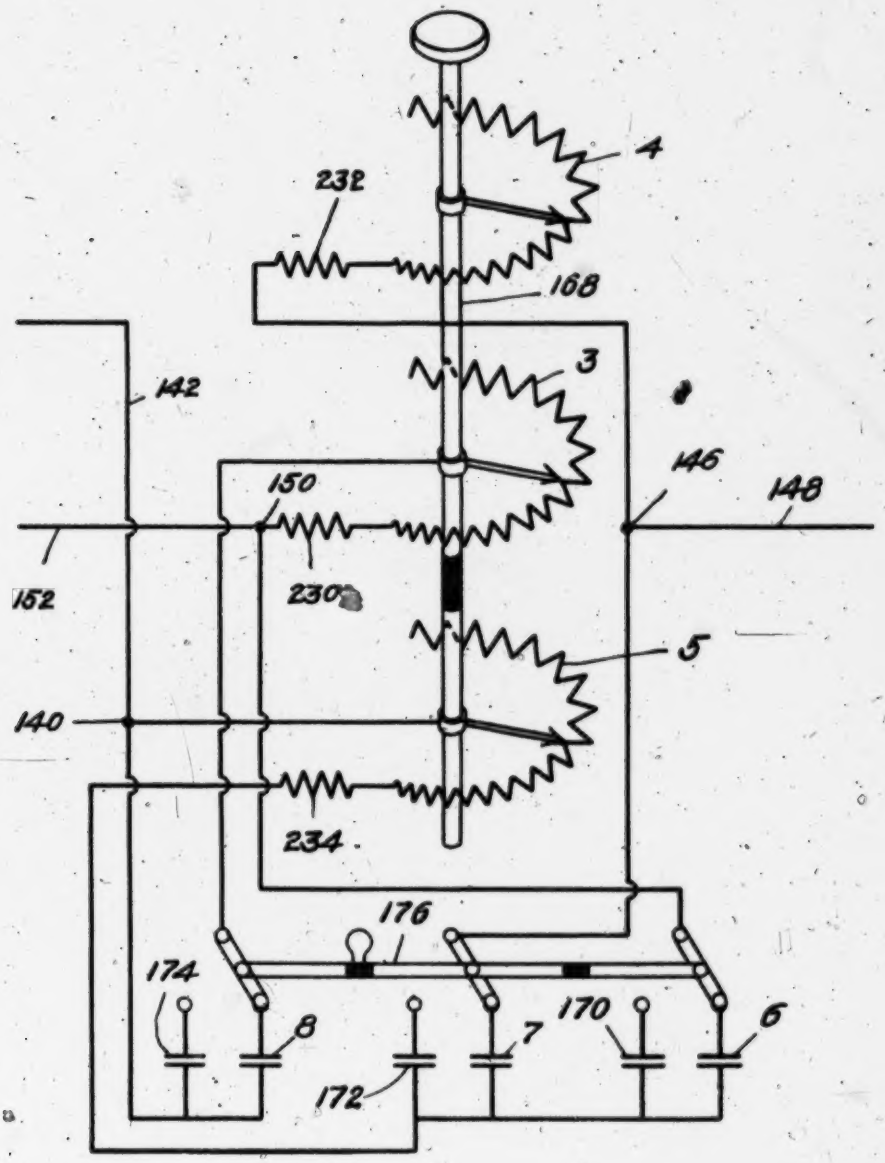


Fig. 10.

HERMON HOSMER SCOTT

INVENTOR

BY David Rines

ATTORNEY

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Sept. 19, 1939. H. H. SCOTT 2,173,426

ELECTRIC SYSTEM

Filed Aug. 30, 1937 7 Sheets-Sheet 6

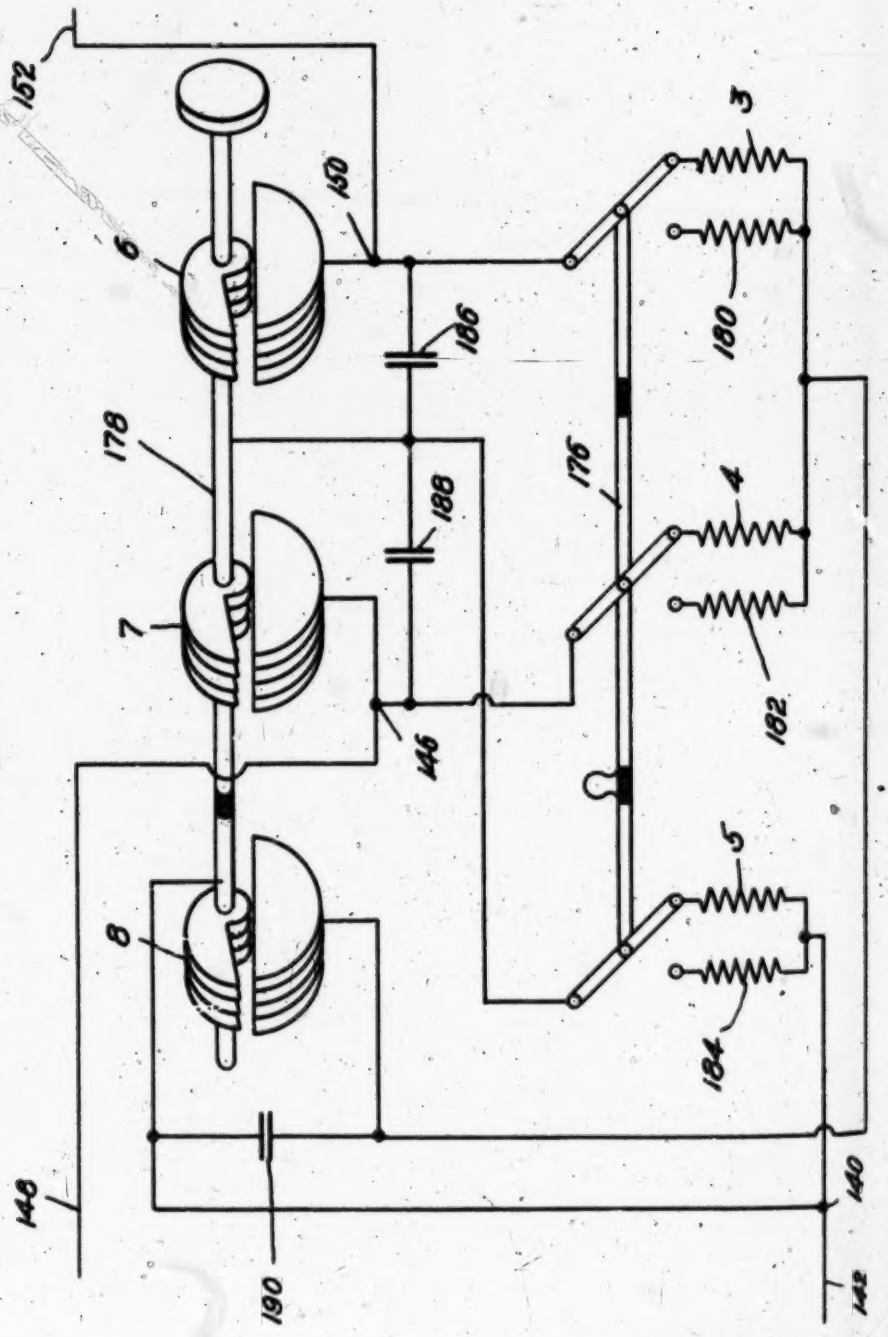


Fig. 11.

Herman Hosmer Scott.
INVENTOR

BY David Rines

ATTORNEY

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Sept. 19, 1939. H. H. SCOTT 2,173,426

ELECTRIC SYSTEM

Filed Aug. 30, 1937 7 Sheets-Sheet 7

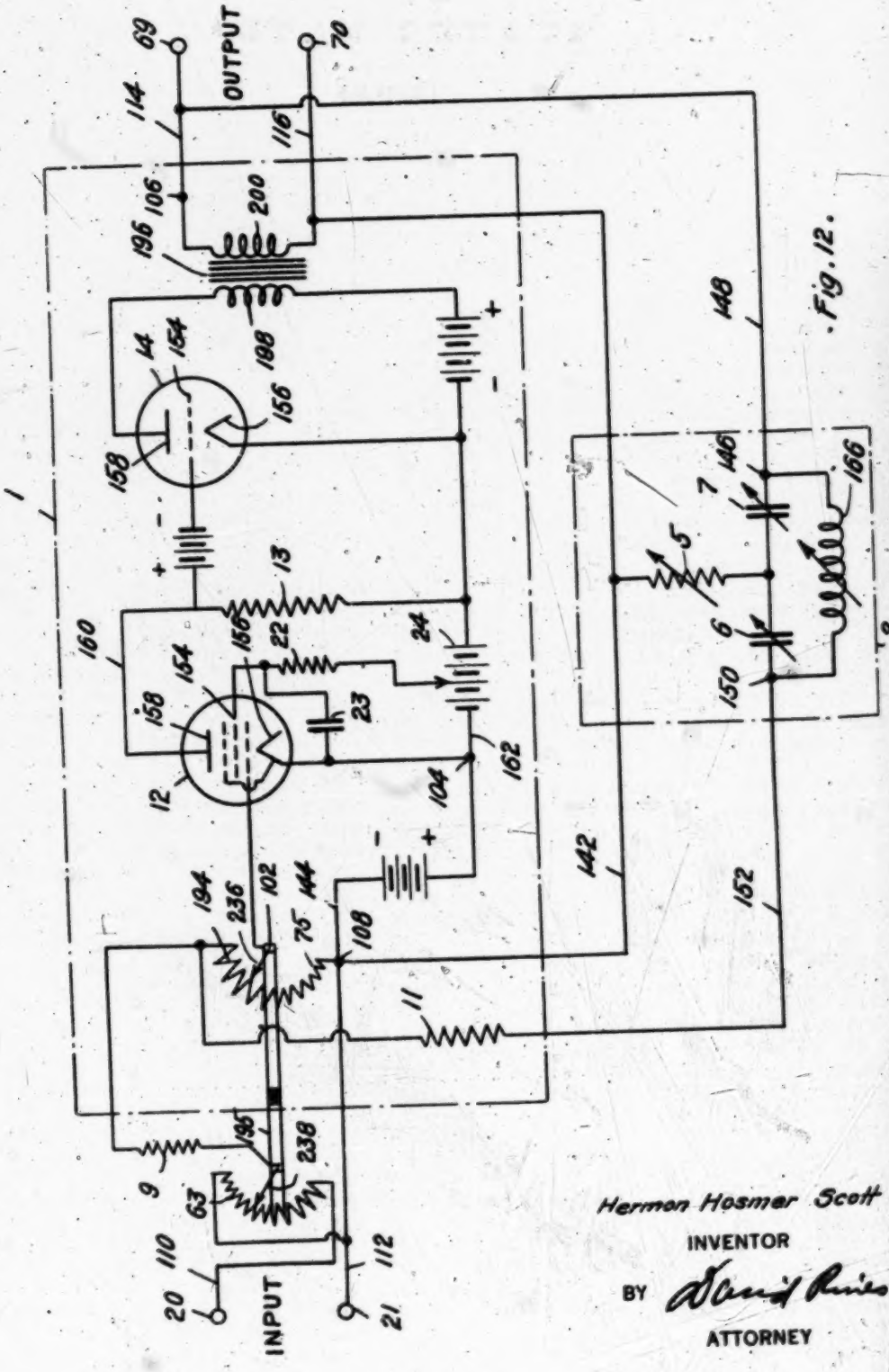


Fig. 12.

Hermon Hosmer Scott

INVENTOR

BY David Rines

ATTORNEY

Patented Sept. 19, 1939 2,173,426

UNITED STATES PATENT OFFICE

2,173,426

ELECTRIC SYSTEM

Hermon Hosmer Scott, Somerville, Mass., assignor to General Radio Company, Cambridge, Mass., a corporation of Massachusetts

Application August 30, 1937, Serial No. 161,831

50 Claims. (Cl. 178—44)

The present invention relates to electric systems, and more particularly to systems for selecting predetermined frequencies from currents or voltages containing a number of different frequencies.

An electric system may transmit or amplify either a single frequency, or a band of frequencies, eliminating or attenuating other frequencies. A single frequency to which an electric system is selective may be regarded as that frequency which the system transmits at substantially maximum amplitude. In the case of a band of frequencies to which the system is selective, that band may be regarded as including those frequencies which are transmitted at a level not less than a predetermined value, say, three decibels, below the maximum transmission in that band.

Various devices are in use or have been proposed for obtaining an electrical circuit which is selective with regard to frequency. The tuned circuits used in radio receivers, and conventional types of filters employing inductances and condensers are examples of widely-used types of selective circuits. Such devices are satisfactory at higher frequencies, but as the frequency is lowered the size of the inductances and condensers becomes increasingly larger. In particular, the inductances for low frequencies are frequently cumbersome and expensive and, because of the large amount of wire with which they must be wound, the resistance is so high as often to make it difficult or even impossible to obtain a satisfactory degree of selectivity.

Further, the use of iron cores in the inductances often results in harmonic distortion and many common types of inductances are subject to magnetic interference; that is, the presence of alternating magnetic fields generated by other electrical equipment will cause interfering voltages to be picked up by the inductances in the filter or tuned circuit, thus causing undesired signals to be present in the output.

A further difficulty is encountered in those cases where it is desired to vary the frequency response or pass band over wide ranges of frequency. Since the problem of varying either inductances or condensers becomes increasingly serious as their size increases, in many variable filter systems only the inductances or the condensers are varied. Such an arrangement is generally satisfactory over a relatively small change in frequency, but for large percentage changes this results in serious impedance shifts and variations in sensitivity.

One common use for sharply-selective circuits is in the analysis of complicated electrical waves, the selective circuits being tuned successively to each of the component frequencies of the wave in order to obtain an individual evaluation of each component. To fix the ideas, an analyzer may be considered to comprise a combination of a selective circuit and some form of indicator for indicating the output or the transmission of said selective circuit. Conventional tuned circuits using inductances and condensers have been used for this purpose, but they are generally bulky, expensive and subject to magnetic interference. A more common method is the heterodyne-type analyzer in which the wave to be measured is heterodyned with a practically sinusoidal wave-form obtained from a vacuum-tube oscillator or other similar source in order to produce a resulting beat note which can be passed through a fixed filter. The frequency to which a system of this type is selective is determined by the frequency of the sinusoidal wave-form with which the unknown wave-form is heterodyned, while the filter circuits themselves remain fixed. One serious disadvantage of this arrangement is that, regardless of the frequency to which the system responds, the band width or selectivity curve has the same width in cycles per second. This often results in unusually sharp selectivity at high frequencies, and broad selectivity at low frequencies.

Selective circuits incorporating resistances and condensers but no inductances have been proposed and used for a few special applications, but the usual circuit of this type does not have as sharp selectivity as is generally desired and also causes a large loss in transmission even at those frequencies where the transmission is greatest.

One of the objects of the present invention is to provide a selective electrical circuit, the response of which may be varied over wide frequency ranges without complicated tuning and switching mechanisms and without any serious shifts in the input and output impedances of the system or its sensitivity. One of the important features of the invention is that this result may be obtained without necessitating the use of any inductances whatsoever, using a frequency-determining system which may consist of resistances and condensers only. The frequency to which such a system is selective can, accordingly, be varied by merely varying resistances or condensers, or both resistances and condensers.

Another object of the present invention is to provide a selective circuit, the selectivity curve

of which is a percentage function of frequency. Such a device is particularly valuable in many types of sound-analysis work where the wave-form being analyzed is obtained from a microphone and amplifier and represents the wave-form of the sound which it is desired to analyze.

Another object of this invention is to provide a selective circuit, the selectivity or band width of which may be varied without changing any of the frequency-determining elements.

A further object is to provide a novel selective amplifier.

Still another object of the invention is to provide a novel wave filter.

Still another object of the invention, furthermore, is to provide a new and improved wave or hamonic analyzer.

Inverse feed-back or degenerative systems are now in use in order to obtain a substantially equal frequency response over wide frequency ranges. A characteristic of such systems is that the over-all amplification or sensitivity is considerably reduced by the introduction of degeneration. A feature of this invention, on the other hand, with the above objects in view, is to employ the inverse feed-back principle, not to obtain equal response over a wide range of frequency, but rather to obtain a response which is sharply selective with regard to frequency. An important feature of this type of inverse feed-back system is that the desirable characteristics are obtained without appreciable loss of sensitivity or amplification, that is, the sensitivity of the system at its point of maximum response may be made the same as without the inverse feed-back arrangement.

Other and further objects will be explained hereinafter and will be particularly pointed out in the accompanying claims.

The invention will now be explained in connection with the accompanying drawings, in which Figure 1 is a diagrammatic and simplified view of circuits and apparatus arranged and constructed according to a preferred embodiment of the present invention; Figure 2 is a further simplified diagrammatic view illustrating a principle underlying the invention; Figure 3 is a view similar to Figure 2, illustrating one form of degeneration network; Figure 4 is a similar view illustrating another form of degeneration network; Figures 5 and 6 are views similar to Figure 2 of modifications; Figure 7 is a diagram illustrating a response curve that is representative of many prior-art types of networks, including the hereinafter described degenerative network; Figure 8 is a similar diagram illustrating a response curve in accordance with the present invention; Figure 9 is a diagram similar to Figure 8 illustrating a modified response curve; and Figures 10 to 13 are views of further modifications.

The response curve shown in Fig. 7, showing the relation between the output voltage and the frequency, is representative of many types of networks, including some combinations of resistance, capacitance and inductance, or mechanical, piezo-electric or magnetostriction devices. The characteristic feature of a curve of this type is that a single frequency or band of frequencies is cancelled out practically entirely, while a reasonable degree of transmission is obtained at other frequencies. In other words, such a device is a form of band-elimination filter.

Such a characteristic can be obtained in a network using only resistances and capacitors such as, for instance, the Wheatstone bridge, including the Wien bridge, and a double-T or parallel-T network. The Wien bridge, for example, illustrated in Fig. 3, is provided with resistors 49, 50, 51 and 52 in its respective arms, and capacitances 54 and 55 respectively in series with and in shunt to the respective resistors 52 and 51. The resistors 49 and 50 are preferably fixed and the resistors 51 and 52 are variable. The parallel-T network consists, as its name implies, of two T networks connected in parallel, as illustrated in Figs. 1 and 4. In Fig. 1, the network includes the circuit elements in the broken line marked 2. It is illustrated as comprising only resistances 3, 4 and 5 (Fig. 1) or 43, 44 and 45 (Fig. 4) and condensers 6, 7 and 8 (Fig. 1) or 46, 46 and 47 (Fig. 4), since this is a convenient form of such a network, but inductances may also be included if desired. The particular T network shown in Figs. 1 and 4 has certain desirable characteristics which will be discussed later.

A bridged-T network may comprise only a single T network as, for instance, the circuit elements 5, 6 and 7 of Fig. 1, or 45, 47 and 48 of Fig. 4, but with another impedance connected directly in shunt with the two series arms 6 and 7 or 46 and 47, respectively. This is illustrated in Fig. 12, the impedance connected between the opposite terminals of capacitances 6 and 7 being represented by the coil 108. It will be understood that the bridge-T, like the parallel-T, network is not restricted to resistors and capacitors. The elements of both networks may comprise any combination of impedances, including inductors.

The desired characteristics for a selective circuit in accordance with the present invention, as previously outlined, may be practically the inverse of that shown in Fig. 7; that is, the circuit should respond to a single frequency or a narrow band of frequencies and should attenuate or eliminate frequencies outside of this range, so as to yield a response curve somewhat of the character illustrated in Fig. 8.

In accordance with a principle of this invention, therefore, a circuit having the characteristic shown in Fig. 7 may be combined with suitable auxiliary apparatus so that the net over-all characteristic shall be as shown in Fig. 8. The inverse of the usual characteristic of the curve is thus obtained, a band-suppression network being employed to produce a band-pass system.

This may be effected in any desired way, as, for example, is diagrammatically illustrated in Fig. 2. The amplifier 25 there diagrammatically illustrated my be of ny desired type, providing an amount of gain, the importance of which will be discussed hereinafter. The amplifier is designated in other figures by other numerals: 1 in Fig. 1, 39 in Fig. 3, 38 in Fig. 4, 86 in Fig. 5 and 91 in Fig. 6. It is shown provided with input terminals 102 and 104, connected to its input circuit, and output terminals 106 and 108, connected to its output circuit. The input terminals 102 and 104 may be connected by conductors 110 and 112 to a source of energy through the medium of terminals 27 and 28, which constitute the input terminals of the system. Such a source of energy is shown in Fig. 1 at 76 but is omitted from Fig. 2 and other figures, for clearness. In other figures, the terminals 27, 28 are represented by other numerals, as 28, 21 (Fig. 1), 41, 42 (Fig. 3), 51, 52 (Fig. 4), 89, 90 (Fig. 5), and 94,

(Fig. 6). In Fig. 2, the terminals 102 and 27 e shown directly connected together by the nductor 110, and the terminal 104 is shown nnected by the conductor 112 to the terminal indirectly, in series with a degenerative net- ork 26, as hereinafter more fully described. It ill be understood, however, that the terminals 4 and 28 may be directly connected together by e conductor 112, as illustrated in Fig. 4, and at other elements may be inserted in the con- uctors 110 and 112, such as the resistor 32 and e condenser 34 of Fig. 4. The terminals 106 and 8 may similarly be connected by conductors 114 nd 116 to any desired load through the medium f terminals 29 and 30, which thus constitute the utput terminals of the system. These output rminals are represented in Fig. 1 as 69, 70, in ig. 3 as 71, 72, in Fig. 4 as 36, 37, in Fig. 5 s 73, 74 and in Fig. 6 as 66, 67.

The said degenerative network 26 is connected etween the input terminals 27 and 28 and the utput terminals 29 and 30 of the system so as o feed back energy from the output circuit of he amplifier to its input circuit. To this end, he input of the feed-back network 26 is shown onnected by conductors 118 and 120 to the out- ut circuit of the amplifier 25, and the output of he network is connected to the input circuit of he amplifier. By thus feeding the input of the etwork back to the input circuit of the amplifier, he net voltage on the input circuit of the ampli- fier is constituted of the combination of the volt- age applied from the voltage source to the termi- nals 27 and 28 and the voltage obtained from the degenerative network 26.

In accordance with the present invention, therefore, selectivity is obtained with the aid of a resistance-capacitance network, but without introducing loss in the normal transmission of the system at the frequencies of maximum trans- mission.

The transmission characteristics of the feed- back network 26 are similar to those shown in Fig. 7, so as to provide maximum attenuation or zero transmission or coupling at that frequency or frequencies where it is desired that the sys- tem as a whole shall provide maximum trans- mission. At other frequencies, which the ampli- fier would normally pass, the network provides a certain amount of transmission and the voltage obtained from the network is fed back to the amplifier input, so that it has a phase difference between 90 and 270 degrees with respect to the voltage applied to terminals 27 and 28. Accord- ingly, as the voltage obtained from the feed-back network increases, it tends to cancel out the net voltage applied to the amplifier, thus reducing the effective gain of the amplifier, or, if the feed- back is sufficiently great, practically eliminating the gain entirely. At the frequency or frequen- cies where the degenerative network provides zero or very low transmission or coupling, the net ef- fective gain of the amplifier is at its maximum or near its maximum, respectively. The result is that the transmission characteristic of the sys- tem as a whole between the input terminals 27 and 28 and the output terminals 29 and 30 has a general characteristic as shown in Fig. 8. It will be seen that the difference in transmission of the system between the frequencies of maximum and minimum transmission, which characteristic may be defined as the maximum suppression of the system, depends upon both the gain of the ampli- fier and the transmission characteristics of the degeneration network. The effect of shifting the amplifier gain is to change appreciably the trans- mission at those frequencies where the transmis- sion is greatest with only a comparatively minor change in the transmission where it is at a mini- mum, thus modifying the selectivity curve and changing the maximum suppression.

It is evident that there are many combinations of apparatus and circuits which will produce this result. The amplifier, for instance, may be one of the more conventional vacuum-tube types em- ploying transformers, resistances, condensers, and, if desired, inductances or transformers as coupling units, or the amplifier may be of some electro-mechanical or other type. The feed-back circuit, also, may be one of many arrangements which will provide the desired characteristics. Since there are a great number of filter and bridge circuits which provide zero or very low transmis- sion at a single frequency or over a band of fre- quencies, it is obvious that the invention covers a large number of possible circuit arrangements. Figs. 3 and 4 show two systems employing common types of resistance-capacitance networks for the inverse feed-back system. In Fig. 3, the inverse feed-back system is illustrated as comprising the before-mentioned Wien bridge. Circuits of this type are widely used for measuring frequency, in which application the suppression of a single frequency or narrow band of frequencies is im- portant. In this use of the Wien bridge, how- ever, the combination with the amplifier and as- sociated apparatus provides an over-all response characteristic which is at a maximum at that frequency to which the bridge is balanced. In a circuit of this type, the response characteristics are determined by the relative values of the re- sistances and the condensers. The characteris- tics of the network may be varied by varying all or some of these components.

As illustrated in Fig. 3, the two opposite ver- tices 122 and 124 of the bridge may be respec- tively connected to the conductor 112 and a con- ductor 126 leading to the input terminal 42. The output circuit of the Wien bridge is thus connected to the input circuit of the amplifier. The vertices 122 and 124 may, however, be di- rectly connected to the conductors 112 and 110, as suggested in Fig. 4. The other two opposite vertices 128 and 130 are shown respectively con- nected by conductors 132 and 134 to the sec- ondary winding 136 of a transformer 40 the pri- mary winding 138 of which is connected by the conductors 114 and 116 to the amplifier output terminals 106 and 108. The output circuit of the amplifier is thus connected to the input circuit of the Wien bridge.

The coupling of the degenerative coupling means is substantially zero at the predetermined single frequency in question, as is true with all networks having an exact null or zero at balance. The coupling transformer 40 merely provides the proper balanced-to-ground circuits for the bridge. It is obvious that transformer 40 could be con- nected between the bridge and the input circuit of the amplifier as well as in the position shown in the diagram. The primary winding 138 of the transformer 40, for example, may be connected to the vertices 122 and 124 of the bridge and the secondary winding 136 to the conductors 112 and 126, the vertices 128 and 130 of the bridge being then directly connected to the conductors 114 and 116.

Fig. 4 represents an improvement over the cir- cuit shown in Fig. 3 in that no transformer 40 is used, since the degeneration network 26 consists

of a three-terminal network having one terminal 148 common to both its input and its output circuits. The terminal 148 is shown connected by a conductor 142 to the terminal 108 and by a conductor 144 to the terminal 104. One of the other two terminals of the network is shown at 146, connected by a conductor 148 to the terminal 106. The third terminal of the network is shown at 150, connected by a conductor 152, through a resistor 38, to the terminal 102. The particular three-terminal network shown is the previously described double-T network, having a characteristic similar to the Wien bridge of Fig. 3, and the frequency of zero transmission may be varied by shifting the resistances 43, 44 and 45, or the condensers 46, 46 and 47, or all six components. It will be noted that in this diagram the feed-back voltage is fed into the amplifier 36 in parallel with the voltage from the source 76 applied to the input terminals 31 and 32. The network consisting of resistances 33 and 35 and condenser 34 is so arranged that neither the feed-back network nor any equipment connected to terminals 31 and 32 has any appreciable effect upon the characteristics of the other. In general an input system of this type provides somewhat less over-all sensitivity than that shown in Fig. 3, but has the important advantage that the input of the system as a whole has one terminal 148 in common with the input of the amplifier.

The two methods of introducing the degeneration voltage into the amplifier, as shown in Figs. 3 and 4, are, of course, interchangeable. Either the series or the parallel arrangement may be used. Any choice between these systems will generally depend upon consideration of the particular application of the invention and, in general, upon the type of circuit or source of energy to be connected to the input of the system. It is also understood that more elaborate arrangements for coupling the feed-back circuit to the amplifier may be used, and they may consist of transformers, additional amplifying stages, etc.

There are several advantages of a system of this type which should be noted. In the first place, if the inverse-feed-back network provides complete suppression at a certain frequency, the amplifier gain is normal at that frequency and not affected by the network. Accordingly, if an adjustable network is used so that its zero transmission frequency is adjustable and if the network is so designed and constructed that practically complete suppression is obtained at any frequency to which it is adjusted, the sensitivity of the amplifier to that frequency will be the same as the sensitivity of the amplifier to the same frequency when the network is not used. It is, accordingly, a relatively simple matter to obtain practically constant sensitivity over a wide frequency range by merely using an amplifier with practically constant gain over that range and a feed-back network which gives practically complete suppression at the passed frequency. Of course, if the amplifier characteristic is not flat over a wide range, or if the feed-back network does not give complete suppression, one of these characteristics may be made to balance the other. It should also be noted that since the feed-back network operates directly into a grid circuit, as illustrated in Fig. 1, or into a high-impedance circuit, and may consist itself of high impedances, no appreciable amount of power need be drawn from the amplifier output by the feed-back system.

It should also be noted that since the feed-back network provides suppression at the frequencies which the system transmits as a whole, it is a simple matter to include several similar networks but tuned or balanced to different frequencies in order to obtain two or more pass bands. Fig. 5 shows an arrangement of this sort consisting of amplifier 56 and two feed-back networks 57 and 58, one operating into the other. Since the combination of these two networks may be made to suppress two frequencies or two bands of frequencies, a characteristic is obtained of the general character shown in Fig. 9. Obviously, other networks may be added to the system to provide other pass bands. It is also, of course, possible to combine the several networks into a single network which will provide the same net results.

According to the preferred embodiment of the invention illustrated in Fig. 1, the amplifier is of the three-stage direct-coupled type, the stages being represented by vacuum tubes 12, 14 and 16, each comprising a cathode 106, a grid 104 and an anode or plate 108. The input circuit of the amplifier, to which the source 76 is connected, may be traced from the terminal 30, by way of the conductor 110, through the resistor 9 and the condenser 10, to the terminal 102, and thence to the grid 104 of the tube 12; and from the grid 104 to the filament or cathode 106, a resistor 21 and a condenser 23, in parallel, to the terminal 104; and finally by way of the conductor 111, to the terminal 31. A resistor 75 may be connected in parallel to the grid 104 and the filament 106. The tube 12 is provided with an output circuit extending from its plate or anode 108, by way of a conductor 109, and through a resistor 13, to a plate battery 24, and thence, by way of a conductor 102, to the filament 104. The input circuit of the second stage 14 of the amplifier is shown connected across the resistor 13, and its output circuit is provided with a similar resistor 15 across which the input circuit of the third stage 16 is connected. The output circuit of the amplifier extends from the plate or anode 108 of the tube 16, by way of a conductor 104, to the terminal 106; and through a resistor 17 to the battery 24, and the terminal 108. Each grid 104 of each tube except the first is galvanically or directly connected to the anode of the preceding tube.

The connection from the cathode 106 of the tube 12 to the resistor 22 is shown as variable, thus to render it possible to vary the gain of the amplifier, thus to adjust the width of the band of frequencies to which the system is selective. The same result may be arrived at by varying the potentiometer 194 of Fig. 12.

An amplifier of this type is not necessary, but the particular arrangement shown is used since the phase shift at low frequencies between the grid 104 of the first tube 12 and the plate 108 of the last tube 16 is always between 180 and 270 degrees. This simplifies the design of the feed-back circuit. Any other type of amplifier can also be used, however, it being merely necessary to keep the total phase shift through the amplifier and the feed-back circuit such that a serious amount of regeneration does not take place. That is, for any frequency for which the amplifier gain is greater than the attenuation in the feed-back network the total phase shift should be between 90 and 270 degrees in order to provide proper degeneration. For these reasons, an amplifier comprising an odd number of stages is frequently desirable and the direct-coupling in-

ture prevents undesirable phase shifts, even at very low frequencies.

The amplifier shown is battery-operated at 24, but, obviously, any suitable power-supply equipment could be used. The heaters or filaments 156 of the tubes must, of course, be operated from suitable batteries or transformers.

The components enclosed within the dotted line marked 2 comprise a feed-back circuit of the double-T network type, as shown in Fig. 4. The particular arrangement shows the resistances 3, 4 and 5 variable, and ganged together for operation by a single control, as is illustrated more particularly in Fig. 10. The output of the network 2 is fed back into the amplifier by an arrangement similar to that shown in Fig. 4, by means of the conductors 162 and 163, the resistor 11 of Fig. 1 corresponding to the resistor 35 of Fig. 4. The transmission characteristic of such a system between the input terminals 20, 21 and the output terminals 68, 70 is similar to that of Fig. 4.

For wave-analysis work, a meter or other indicating device 19 may be connected to the output terminals. This indicating device will then show the relative intensity of each component in the wave-form, when resistors 3, 4 and 5 and condensers 6, 7 and 8 are adjusted so that the system is selective to that particular component.

The parallel-T network, including resistances and capacitances only, is shown in the preferred embodiment of the invention of Fig. 1, because this particular type of network is extremely useful at audio frequencies. One condition of balance for such a network is obtained when capacitance 8 equals capacitance 7, each equaling one-half of capacitance 6, when resistance 3 equals resistance 4, each resistance 3 and 4 equaling two times resistance 5, and when the reactance of capacitance 6 is equal in magnitude to resistance 5. This condition of balance for the parallel-T network, as shown in Fig. 1, results in very convenient values for the circuit elements in this network. Obviously, this combination of values lends itself readily to simultaneous operation of the resistances or the condensers by means of a common control. A convenient method for varying such a network over wide ranges at lower frequencies is to employ three variable resistances which are operated by a common control, as illustrated in Fig. 10. By switching various sizes of condensers into the circuit as components 6, 7 and 8, the frequency to which the system is selective may be varied in steps. At higher frequencies, it is sometimes desirable to use variable condensers, which may or may not be connected to a common shaft, and to keep the three resistors fixed, or to vary them in steps by means of a switch. At higher frequencies, a bridged-T network is sometimes more satisfactory than the double-T network on the basis of manufacturing costs and ease of control.

Obviously, the frequency to which this system is selective may be varied by varying the elements in the parallel-T network. A convenient arrangement at lower frequencies is continuously to adjust the three resistances 3, 4 and 5 simultaneously by means of a single control arm 168, and to shift by steps the condensers 6, 7 and 8 or the condensers 170, 172 and 174, respectively, by means of a multi-pole switch 176, as illustrated in Fig. 10. At higher frequencies it may be simpler to use continuously variable condensers 6, 7 and 8 operated by a single control arm 172 and to switch by steps the resistances 3, 4 and 5 or other resistances 180, 182 and 184, respectively, as illustrated in Fig. 11. The condensers 6, 7 and 8 of Fig. 11 are shown bridged by fixed condensers 186, 188 and 190, respectively, for limiting the frequency range. The resistors 230, 232, 234, in series with resistors 3, 4 and 5, respectively, as shown in Fig. 10 are for a similar purpose.

A similar simultaneous adjustment of various of the elements of the Wien-bridge structure of Fig. 3 may be effected as illustrated and described in Letters Patent No. 1,983,447 to Robert F. Field, issued December 4, 1934.

It will be understood that the features illustrated in Figs. 10 and 11 may be embodied in the system of Fig. 1 or other figures, and that the same is true of the other modifications illustrated and described herein. The passive network 26 and the additional amplifier 192 in series therewith illustrated in Fig. 13 may, for example, be embodied in any of the other figures, typified in Fig. 2.

Although the basic circuits shown in Figs. 1, 2, 3, 4 and 5 will provide a certain amount of gain in the pass bands, it is understood that, in some cases, it may be desirable to use such circuits where no gain is necessary or required. Under these conditions it is merely necessary to use the system in conjunction with an attenuator 63, as shown in Fig. 6, which attenuator may be employed to control the sensitivity of the system. The circuit shown includes the amplifier 61, and a feed-back network 62, and functions similarly to the arrangement shown in Fig. 2. By reason of the attenuator 63, however, the over-all amplification or sensitivity may be reduced to any desired value. This attenuator 63, instead of being connected to the output of the system, as shown in Fig. 6, could be connected to the input, as illustrated in Fig. 12. According to the present invention, it is possible to vary the selectivity merely by shifting the gain of the amplifier part of the system without necessitating the changing of any of the frequency- determining elements of the system. This may be effected without changing the over-all sensitivity, if desired, by simultaneously adjusting the attenuator 63 and the potentiometer 194. The potentiometer 194 and the attenuator 63, which are both shown in the input circuit of the first stage, may be actuated simultaneously from a common shaft 196. For constant over-all sensitivity, as previously mentioned, it is obviously necessary to vary the attenuator 63 in such a direction as to tend to decrease the sensitivity when the amplifier gain control 194 is varied in such a direction as to tend to increase the sensitivity, and vice versa.

For the sake of variety, the circuit of Fig. 12 is illustrated as comprising an even number of amplifying stages, respectively, and the phase reversal is illustrated as effected by means of a transformer 198, the primary winding 199 of which is connected in the output circuit of the last amplifier stage, and the secondary winding 200 of which is shown connected to the conductors 114 and 116. By phase reversal, it is intended to denote the before-described shifting of the phase between 90 degrees and 270 degrees.

It will be understood that phase reversals may be effected in other ways also. For example, a coupling may be provided between the output circuit of an even-numbered stage of amplification and the input circuit of a previous even-numbered stage of amplification or between the output of an odd-numbered stage and the input of

a previous odd-numbered stage. If the degeneration network includes a transformer or other means for reversing the phase, the degenerative coupling may be from the output of an even-numbered stage of amplification into the input of an odd-numbered stage, or vice versa.

Other modifications and changes will also occur to persons skilled in the art, and all such are considered to fall within the spirit and scope of the present invention, as defined in the appended claims.

What is claimed is:

1. An electric system having, in combination, a source of energy, a multi-stage amplifier having an input circuit coupled to the source and an output circuit, one of the stages of the amplifier being coupled directly to a previous stage of the amplifier, means for degeneratively coupling the output circuit to the input circuit, and means for rendering the degenerative coupling substantially ineffective at a predetermined frequency or frequencies, the system as a whole having parameters such as to provide substantially maximum transmission at the said predetermined frequency or frequencies in order to render the system as a whole selective at the said predetermined frequency or frequencies and such that at frequencies substantially removed from said predetermined frequency or frequencies substantially the whole output voltage of the amplifier is fed degeneratively through the network back to the input circuit of the amplifier.

2. An electric system having, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, and means comprising a network degeneratively coupling non-inductively the output circuit to the input circuit in order to reduce the effective gain of the amplifier, the said network having substantially minimum transmission at a predetermined frequency or frequencies, and the system as a whole having parameters such as to provide substantially maximum transmission at the said predetermined frequency or frequencies in order to render the system as a whole selective at the said predetermined frequency or frequencies and such that at frequencies substantially removed from said predetermined frequency or frequencies substantially the whole output voltage of the amplifier is fed degeneratively through the network back to the input circuit of the amplifier.

3. An electric system having, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means comprising a plurality of networks for degeneratively coupling the output circuit to the input circuit, the respective networks having substantially minimum transmission characteristics at respective predetermined frequencies, and the system as a whole having parameters such as to provide substantially maximum transmission at the said respective predetermined frequencies in order to render the system as a whole selective to the said respective predetermined frequencies and such that at frequencies substantially removed from said predetermined frequencies a sufficiently large fraction of the output voltage is fed back degeneratively to the input circuit of the amplifier so as to cancel substantially the entire gain of the amplifier.

4. An electric system having, in combination, a source of energy, a direct-current multi-stage amplifier having an input circuit coupled to the source and an output circuit, and means for degeneratively coupling the output circuit to the input circuit in order to reduce the effective gain of the amplifier, the said means having substantially minimum transmission at a predetermined frequency or frequencies, the system as a whole having parameters such as to provide substantially maximum transmission at the said predetermined frequency or frequencies in order to render the system as a whole selective at the said predetermined frequency or frequencies and such that at frequencies substantially removed from said predetermined frequency or frequencies a sufficiently large fraction of the output voltage is fed back degeneratively to the input circuit of the amplifier so as to cancel substantially the entire gain of the amplifier.

5. An electric system selective to predetermined frequencies having, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means for degeneratively coupling the output circuit to the input circuit in order to reduce the effective gain of the amplifier, and means for rendering the degenerative coupling substantially ineffective at said predetermined frequencies, said means including one or more variable circuit elements for the purpose of varying said predetermined frequencies, the system as a whole having parameters such as to provide substantially maximum transmission at the said predetermined frequencies in order to render the system as a whole selective to the said predetermined frequencies.

6. An electric system having maximum transmission at a single frequency and comprising, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, and means for degeneratively coupling the output circuit to the input circuit in order to reduce the effective gain of the amplifier, the said means having substantially minimum transmission at said single frequency, and including one or more variable circuit elements, and the system as a whole having parameters such as to provide substantially maximum transmission at the said single frequency in order to render the system as a whole selective at the said single frequency.

7. An electric system having maximum transmission at a single frequency and comprising, in combination, a source of energy, a direct-coupled multi-stage amplifier having an input circuit coupled to the source and an output circuit, and means for degeneratively coupling the output circuit to the input circuit, the said means comprising a network having common input and output terminals and unprovided with mutually inductive elements, but having substantially zero coupling at said single frequency and including one or more variable circuit elements for the purpose of adjusting the frequency to which the system is selective.

8. An electric system giving peaked response, selectively, at a predetermined frequency or within a predetermined band of frequencies having, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means for degeneratively coupling the output circuit to the input circuit in order to reduce the effective gain of the amplifier, and means for rendering said degenerative coupling substantially ineffective at said predetermined frequency or frequencies, said means including two or more variable circuit elements for varying the said predetermined frequency or frequencies, and means for simultaneously ad-

justing two or more of the variable circuit elements.

9. An electric system comprising a network and selective with regard to a predetermined frequency or frequencies as predetermined by the characteristics of the component circuit elements of the network, the said electric system having, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means comprising the network for degeneratively coupling the output circuit to the input circuit in order to reduce the effective gain of the amplifier, and means for rendering said degenerative coupling substantially ineffective at said predetermined frequency or frequencies, said means including means for switching one or more of the circuit elements into or out of the degenerative coupling network for the purpose of changing the frequency or frequencies to which the system is selective.

10. An electric system having maximum transmission at a single frequency and comprising, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means for degeneratively coupling the output circuit to the input circuit, said means having substantially zero transmission at said single frequency and comprising a network containing resistances and capacitances only, and means for varying one or more of said resistances and capacitances for the purpose of adjusting the frequency to which the system is selective, the system having parameters such that the system as a whole provides substantially maximum transmission at the said single frequency.

11. An electric system selective to predetermined frequencies and comprising, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means for degeneratively coupling the output circuit to the input circuit, and means for rendering the degenerative coupling means substantially ineffective at said predetermined frequencies, the first-named means comprising a three-terminal network having one terminal common to the input and output circuits and the other two terminals respectively connected to the input and output circuits, the system as a whole having parameters such as to provide substantially maximum transmission at the said predetermined frequencies in order to render the system as a whole selective to the said predetermined frequencies.

12. An electric system having maximum transmission at a single frequency and comprising, in combination, a source of energy, a direct-coupled multi-stage amplifier having an input circuit coupled to the source and an output circuit, means for degeneratively coupling the output circuit to the input circuit, said means having substantially zero coupling at said single frequency and comprising a Wheatstone bridge having a plurality of circuit elements comprising resistances in all four arms thereof, a capacitance in series with one of said resistances, and a second capacitance in parallel with another of said resistance and means for varying one or more of the circuit elements in said bridge for the purpose of adjusting the frequency to which the system is selective.

13. An electric system selective to a single frequency and comprising, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means for degeneratively coupling the output circuit to the input circuit, said means having substantially zero coupling at said single frequency and comprising a parallel-T network, and means for adjusting one or more of the circuit elements in said network for the purpose of selecting the frequency to which the system is selective.

14. An electric system selective with regard to frequency and comprising, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means comprising a parallel-T network containing resistances and capacitances only for degeneratively coupling the output circuit to the input circuit, said network having substantially zero transmission at a frequency determined by the characteristics of its component elements, means for adjusting all resistances therein simultaneously for continuous adjustment of the frequency to which the system is selective, and means comprising a multi-pole switch for switching the capacitances into said circuit selectively to adjust in steps the frequency to which the system is selective.

15. An electric system having, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means comprising a parallel-T network containing a plurality of resistors and a plurality of capacitors for degeneratively coupling the output circuit to the input circuit, the said network having substantially zero transmission at a frequency determined by the characteristics of its component elements, means for adjusting the capacitors continuously, and means for switching the resistors into circuit selectively.

16. An electric system having maximum transmission at a single frequency and comprising, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means for degeneratively coupling the output circuit to the input circuit, said means having substantially zero coupling at said single frequency and comprising a bridged-T network, and the system as a whole having parameters such as to provide substantially maximum transmission at the said single frequency in order to render the system as a whole selective at the said single frequency.

17. An electric system selective to predetermined frequencies comprising, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means comprising a network for degeneratively coupling the output circuit to the input circuit, and means for rendering said degenerative coupling substantially ineffective at said predetermined frequencies and for varying the gain of said amplifier for the purpose of varying the selectivity of the system, the system as a whole having parameters such as to provide substantially maximum transmission at the said predetermined frequencies in order to render the system as a whole selective at the said predetermined frequencies.

18. An electric system selective to predetermined frequencies having, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means for degeneratively coupling the output circuit to the input circuit, and means for rendering the degenerative coupling means substantially ineffective at said predetermined frequencies, said degenerative coupling means comprising a passive network and a second amplifier, the system as a whole having parameters such as to provide substantially maximum transmission

at the said predetermined frequencies in order to render the system as a whole selective at the said predetermined frequencies.

19. An electric system comprising a first circuit having an input circuit and an output circuit, a second circuit having an input circuit and an output circuit and having a characteristic curve such that the transmission of the second circuit shall be rendered substantially ineffective at a predetermined frequency or frequencies, and means for coupling the second-named input circuit to the first-named output circuit and the second-named output circuit to the first-named input circuit to feed back energy from the first-named output circuit to the first-named input circuit through the second circuit, the system comprising means for effecting a reversal of phase between the voltage in the first-named input circuit and the voltage applied to the first-named input circuit by the second-named output circuit, the system as a whole having parameters such as to provide substantially maximum transmission at the said predetermined frequency or frequencies in order to render the system as a whole selective to the said predetermined frequency or frequencies.

20. An electric system comprising an amplifier having an input circuit and an output circuit, a network having a characteristic curve such that the transmission of the network shall be rendered substantially ineffective at a predetermined frequency or frequencies, and means for degeneratively coupling the output circuit to the input circuit to feed back energy from the output circuit to the input circuit through the network, the system comprising means for effecting a reversal of phase between the voltage of the input circuit and the voltage applied to the input circuit by the network, the system as a whole having parameters such as to provide substantially maximum transmission at the said predetermined frequency or frequencies in order to render the system as a whole selective at the said predetermined frequency or frequencies.

21. An electric system comprising an amplifier having an input circuit and an output circuit, a three-terminal network having a characteristic curve such that the transmission of the network shall be rendered substantially ineffective at a predetermined frequency or frequencies, and means connecting two of the terminals of the network to the output circuit and one of the said two terminals and the third terminal of the network to the input circuit to feed back energy from the output circuit to the input circuit through the network, the system comprising means for effecting a reversal of phase between the voltage in the input circuit and the voltage applied to the input circuit by the network, the system as a whole having parameters such as to provide substantially maximum transmission at the said predetermined frequency or frequencies in order to render the system as a whole selective at the said predetermined frequency or frequencies.

22. An electric system comprising a network and selective with regard to frequency as predetermined by the characteristics of the component circuit elements of the network, the said electric system having, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, and means comprising the network for degeneratively coupling the output circuit to the input circuit, the network having common input and output terminals and having substantially zero transmission at the predetermined frequency.

23. An electric system comprising a network and selective with regard to frequency as predetermined by the characteristics of the component circuit elements of the network, the said electric system having, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means comprising the network for degeneratively coupling the output circuit to the input circuit, the network having common input and output terminals and having substantially zero transmission at the predetermined frequency, and means for adjusting said component elements to adjust the predetermined frequency.

24. An electric system comprising a network and selective with regard to frequency as predetermined by the characteristics of the component circuit elements of the network, the said electric system having, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, the amplifier comprising more than one stage, one of the stages being directly coupled to a previous stage, and means comprising the network for degeneratively coupling the output circuit to the input circuit, the network having substantially zero transmission at the predetermined frequency.

25. An electric system comprising a network and selective with regard to frequency as predetermined by the characteristics of the component circuit elements of the network, the said electric system having, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, the amplifier comprising more than one stage, one of the stages being directly coupled to a previous stage, means comprising the network for degeneratively coupling the output circuit to the input circuit, the network having substantially zero transmission at the predetermined frequency, and means for adjusting said component elements to adjust the predetermined frequency.

26. An electric system comprising a network and selective with regard to frequency as predetermined by the characteristics of the component circuit elements of the network, the said electric system having, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, the amplifier comprising a plurality of tubes each having a cathode, a grid and an anode, input and output circuits for each tube comprising, respectively, the grid and the cathode, and the plate and the cathode, of the respective tubes, each grid of each tube except the first being galvanically connected to the plate of the preceding tube, and means comprising the network for degeneratively coupling the output circuit of the amplifier to the input circuit of the amplifier, the network having a common input terminal and output terminal and having substantially zero transmission at the predetermined frequency.

27. An electric system comprising a network and selective with regard to frequency as predetermined by the characteristics of the component circuit elements of the network, the said electric system having, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, the amplifier comprising a plurality of tubes each having a cathode, a grid and an anode, input and output circuits for each tube comprising, respectively, the grid and the cathode, and the plate and the

cathode, of the respective tubes, each grid of each tube except the first being galvanically connected to the plate of the preceding tube, means comprising the network for degeneratively coupling the output circuit of the amplifier to the input circuit of the amplifier, the network having a common input terminal and output terminal and having substantially zero transmission at the predetermined frequency, and means for adjusting said component elements to adjust the predetermined frequency.

28. An electric system selective with regard to frequency and comprising, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means comprising a bridged-T network for degeneratively coupling the output circuit to the input circuit, the network having substantially zero transmission at a frequency determined by the characteristics of its component elements, and means for adjusting said component elements for adjustment of the frequency to which the system is selective.

29. An electric system selective with regard to frequency having, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means comprising a parallel-T network containing a plurality of resistors and a plurality of capacitors for degeneratively coupling the output circuit to the input circuit, the said network having substantially zero transmission at a frequency determined by the characteristics of its component elements, and means for adjusting the values of the component parts of said network for the purpose of changing the frequency to which the system is selective.

30. An electric system selective with regard to frequency having, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means comprising a parallel-T network containing a plurality of resistors and a plurality of capacitors for degeneratively coupling the output circuit to the input circuit, the said network having substantially zero transmission at a frequency determined by the characteristics of its component elements, and means for adjusting simultaneously the values of two or more of the component parts of said network for the purpose of changing the frequency to which the system is selective.

31. An electric system selective with regard to frequency and comprising, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means comprising a three-terminal network containing resistances and capacitances only for degeneratively coupling the output circuit to the input circuit, said network having substantially zero transmission at a frequency determined by the characteristics of its component elements, means for adjusting all resistances therein simultaneously for continuous adjustment of the frequency to which the system is selective, and means comprising a multi-pole switch for switching the capacitances into said circuit selectively to adjust in steps the frequency to which the system is selective.

32. An electric system selective with regard to frequency having, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means comprising a three-terminal network containing a plurality of resistors and a plurality of capacitors for degeneratively coupling the output circuit to the input circuit, the said network having substantially zero transmission at a frequency determined by the characteristics of its component elements, means for adjusting the capacitors continuously, and means for switching the resistors into the circuit selectively.

33. An electric system selective with regard to frequency having, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means comprising a three-terminal network containing a plurality of resistors and a plurality of capacitors for degeneratively coupling the output circuit to the input circuit, the said network having substantially zero transmission at a frequency determined by the characteristics of its component elements, and means for adjusting the values of the component parts of said network for the purpose of changing the frequency to which the system is selective.

34. An electric system selective with regard to frequency and comprising, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means comprising a parallel-T network containing resistances and capacitances only for degeneratively coupling the output circuit to the input circuit, said network having substantially zero transmission at a frequency determined by the characteristics of its component elements, means for adjusting all resistances therein simultaneously for continuous adjustment of the frequency to which the system is selective, means comprising a multi-pole switch for switching the capacitances into said circuit selectively to adjust in steps the frequency to which the system is selective, and means for indicating the output voltage or energy of the system.

35. An electric system having, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means comprising a parallel-T network containing a plurality of resistors and a plurality of capacitors for degeneratively coupling the output circuit to the input circuit, the said network having substantially zero transmission at a frequency determined by the characteristics of its component elements, means for adjusting the capacitors continuously, means for switching the resistors into the circuit selectively, and means for indicating the output voltage or energy of the system.

36. An electric system, selective with regard to frequency and comprising, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means comprising a three-terminal network containing resistances and capacitances only for degeneratively coupling the output circuit to the input circuit, said network having substantially zero transmission at a frequency determined by the characteristics of its component elements, means for adjusting all resistances therein simultaneously for continuous adjustment of the frequency to which the system is selective, means comprising a multi-pole switch for switching the capacitances into said circuit selectively to adjust in steps the frequency to which the system is selective, and means for indicating the output voltage or energy of the system.

37. An electric system having, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means comprising a three-terminal network containing a plurality of resistors and a plurality

of capacitors for degeneratively coupling the output circuit to the input circuit, the said network having substantially zero transmission at a frequency determined by the characteristics of its component elements, means for adjusting the capacitors continuously, means for switching the resistors into the circuit selectively, and means for indicating the output voltage or energy of the system.

38. An electric system, selective with regard to frequency and comprising, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means for degeneratively coupling the output circuit to the input circuit, said means comprising a network having common input and output terminals, said network having substantially zero transmission at a frequency determined by the characteristics of the component elements, and means for adjusting said component elements for adjustment of the frequency to which the system is selective.

39. An electric system selective with regard to frequency having, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means comprising a parallel-T network containing a plurality of resistors and a plurality of capacitors for degeneratively coupling the output circuit to the input circuit, the said network having substantially zero transmission at a frequency determined by the characteristics of its component elements, and means for adjusting the transmission characteristics of said network for the purpose of adjusting the selectivity of the system.

40. An electric system, selective with regard to frequency, having, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, means comprising a parallel-T network containing a plurality of resistors and a plurality of capacitors for degeneratively coupling the output circuit to the input circuit, the said network having substantially zero transmission at a frequency determined by the characteristics of its component elements, and means for adjusting the gain of said amplifier for the purpose of adjusting simultaneously the gain and selectivity of the system.

41. An electric system, selective with regard to frequency and comprising, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, and means comprising a parallel-T network containing resistances and capacitances only for degeneratively coupling the output circuit to the input circuit, said network having substantially zero transmission at a frequency determined by the characteristics of its component elements, and said amplifier having an odd number of amplifying stages in order to provide substantially 180 degrees phase shift between the input and output circuits.

42. An electric system, selective with regard to frequency and comprising, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, and means comprising a parallel-T network containing resistances and capacitances only for degeneratively coupling the output circuit to the input circuit, said network having substantially zero transmission at a frequency determined by the characteristics of its component elements, and said amplifier comprising a plurality of amplifying stages including vacuum tubes, with the grid of each tube except the first connected directly to the plate of the tube in the preceding stage.

43. An electric system, selective with regard to frequency and comprising, in combination, a source of energy, an amplifier having an input circuit coupled to the source and an output circuit, and means comprising a parallel-T network containing resistances and capacitances only for degeneratively coupling the output circuit to the input circuit, said network having substantially zero coupling at a frequency determined by the characteristics of its component elements, and said amplifier including means for reversing the phase between the input and output circuits.

44. An electric system comprising a plurality of successively connected vacuum tubes each having a cathode, a grid and an anode, an input circuit of each tube connected to the grid and the cathode and an output circuit connected to the anode and the cathode of each tube, the grid of one or more of the tubes being galvanically connected to the anode of the preceding tube, said one or more of the tubes having a resistor and a condenser in parallel in common to its or their input and output circuits.

45. An electric system comprising a plurality of successively connected tubes each having a cathode, a grid and an anode, an input circuit of each tube connected to the grid and the cathode and an output circuit connected to the anode and the cathode of each tube, the grid of one or more of the tubes being galvanically connected to the anode of the preceding tube, said one or more of the tubes having a resistor in common to its or their input and output circuits, the said resistor being connected also in one of the tubes preceding the said one or more of the tubes.

46. An electric system comprising a plurality of successively connected vacuum tubes each having a cathode, a grid and an anode, an input circuit of each tube connected to the grid and the cathode and an output circuit connected to the anode and the cathode of each tube, the grid of one or more of the tubes being galvanically connected to the anode of the preceding tube, said one or more of the tubes having a resistor in common to its or their input and output circuits, the said resistor being connected also in the input circuit of one of the tubes preceding the said one or more of the tubes.

47. An electric system comprising a plurality of successively connected vacuum tubes each having a cathode, a grid and an anode, an input circuit of each tube connected to the grid and the cathode and an output circuit connected to the anode and the cathode of each tube, the grid of one or more of the tubes being galvanically connected to the anode of the preceding tube, said one or more of the tubes having a resistor and a condenser in parallel in common to its or their input and output circuits, the said resistor and condenser being connected also in one of the tubes preceding the said one or more of the tubes.

48. An electric system comprising a plurality of successively connected vacuum tubes each having a cathode, a grid and an anode, an input circuit of each tube connected to the grid and the cathode and an output circuit connected to the anode and the cathode of each tube, the grid of one or more of the tubes being galvanically connected to the anode of the preceding tube, said one or more of the tubes having a resistor and a condenser in parallel in common to its or their input and output circuits, the said resistor and condenser being connected also in the input circuit of

one of the tubes preceding the said one or more of the tubes.

49. An electric system comprising a plurality of vacuum tubes each having a cathode, a grid and an anode, an input circuit of each tube connected to the grid and the cathode and an output circuit connected to the anode and the cathode of each tube, the grid of one or more of the tubes being galvanically connected to the anode of the preceding tube, said one or more of the tubes having a resistor in common to its or their input and output circuits, means for degeneratively coupling the output of the system to the input of the system, and means for rendering said coupling means ineffective at a predetermined frequency.

50. An electric system comprising a plurality of vacuum tubes each having a cathode, a grid and an anode, an input circuit of each tube connected to the grid and the cathode and an output circuit connected to the anode and the cathode of each tube, the grid of one or more of the tubes being galvanically connected to the anode of the preceding tube, said one or more of the tubes having a resistor and a condenser in parallel in common to its or their input and output circuits, means for degeneratively coupling the output of the system to the input of the system, and means for rendering said coupling means ineffective at a predetermined frequency.

HERMON H. SCOTT.

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DEFENDANT'S EXHIBIT O-14

Halliburton Patent No. 2,201,311

[Endorsed]: Filed Nov. 4, 1942.

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May 21, 1940. E. P. HALLIBURTON 2,201,311

APPARATUS FOR INDICATING THE POSITION OF DEVICES IN PIPES

Filed Dec. 24, 1936 2 Sheets-Sheet 1

Fig. 1.

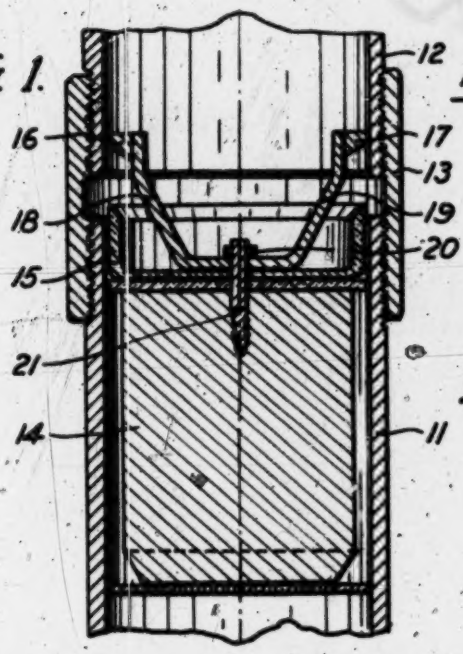


Fig. 3.

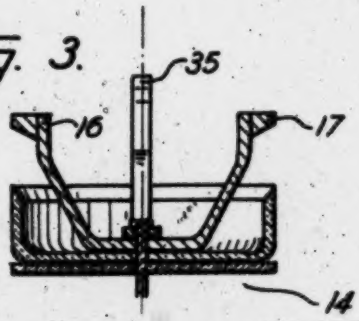


Fig. 4.

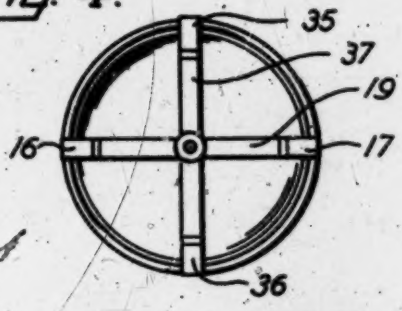


Fig. 2.

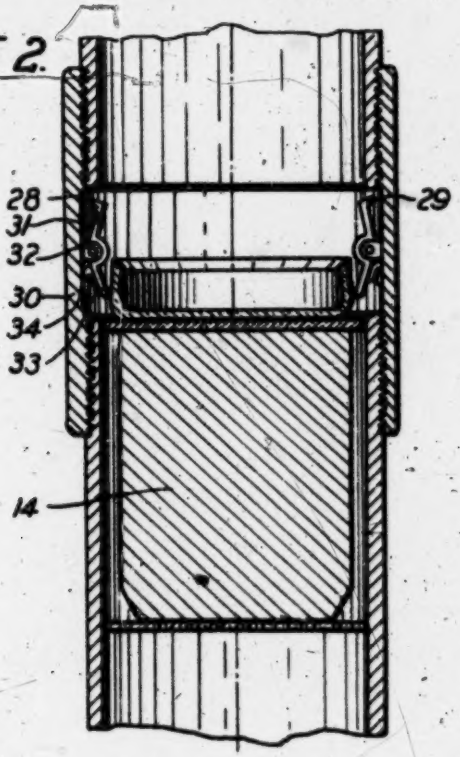


Fig. 10.

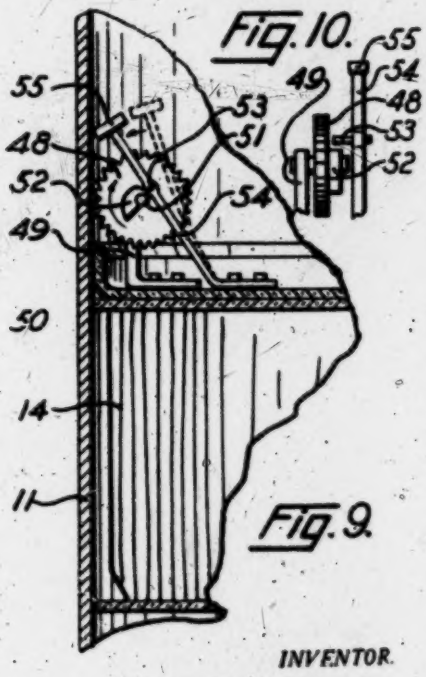


Fig. 9.

INVENTOR.
Erle P. Halliburton.
BY Earl Babcock
ATTORNEY

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May 21, 1940. E. P. HALLIBURTON 2,201,311

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Filed Dec. 24, 1936 2 Sheets-Sheet 2

Fig. 5.

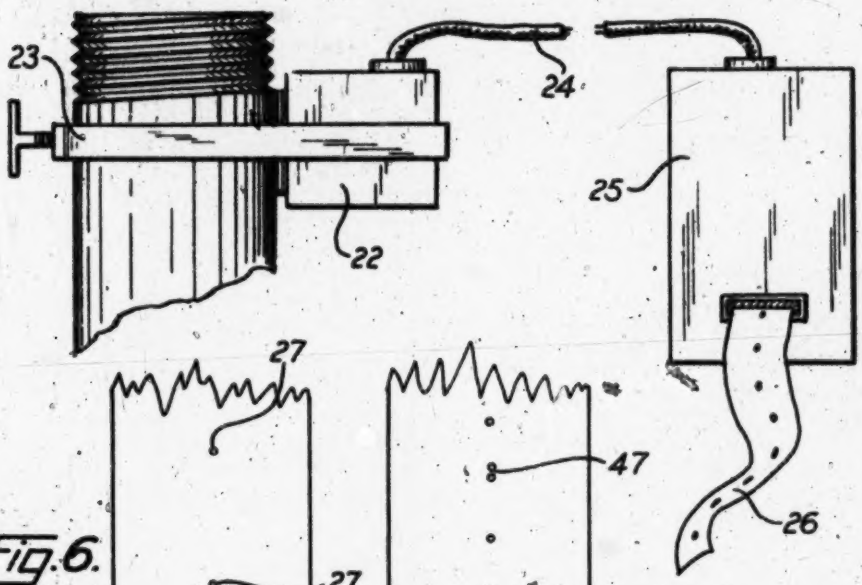


Fig. 6.

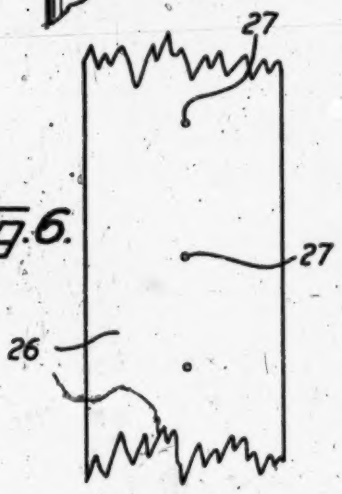


Fig. 7.

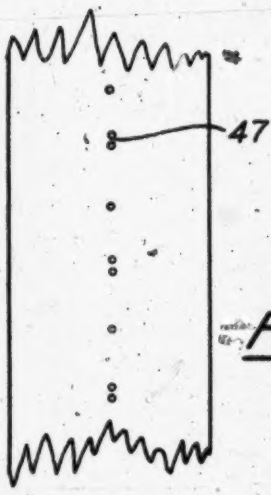
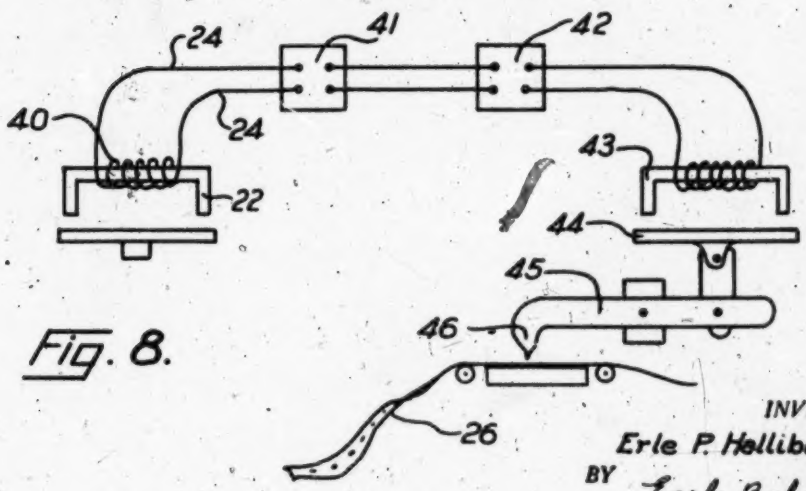


Fig. 8.



INVENTOR.
Erle P. Halliburton.
BY Earl Babcock.
ATTORNEY

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UNITED STATES PATENT OFFICE

2,201,311

APPARATUS FOR INDICATING THE POSITION OF DEVICES IN PIPES

Erle P. Halliburton, Los Angeles, Calif., assignor to Halliburton Oil Well Cementing Company, Duncan, Okla.

Application December 24, 1936, Serial No. 117,504

6 Claims. (Cl. 181—0.5)

This invention relates to the apparatus for indicating the position of devices passing through pipes and more particularly to means for indicating the position of the devices by the transmission of sound or vibrations through the pipes.

It is often desirable to know the position of a plug or other element moving through a pipe or casing. For example, in the cementing of an oil well where one or more plugs are used in placing the cement in a particular part of the well, it is desirable to keep track of the position of at least the upper plug. It has been common practice heretofore to use a measuring line for this purpose. Examples of means for accomplishing this are disclosed in my prior patents, No. 1,369,891, granted March 1, 1921, for Method and means for cementing oil wells, and No. 1,892,037, granted November 20, 1928, for Well sounding device.

The use of a measuring line as illustrated in the patents mentioned above has certain disadvantages. The well is subjected to high pressures during the cementing operations, so the measuring line must travel through a stuffing box or gland and this sometimes causes difficulties. Also, the measuring line sometimes breaks in the well and becomes tangled and difficult to remove. Moreover, and particularly in very deep wells, it is not always certain that the lower end of the measuring line is following the plug and the readings of distance are not always accurate because the measuring line stretches.

It is also to be noted that where a measuring line is employed in the cementing of an oil well an indication can be obtained only of the position of the upper plug.

It is an object of the present invention to overcome these and other difficulties by doing away with the measuring line altogether.

It is another object of the invention to devise an apparatus by which the position of a plug or other object in the casing of a well, or the like, can be accurately determined at all times as the result of vibrations set up in the casing.

It is still another object of the invention to devise means for determining or recording the position of a plurality of plugs or like devices within a casing.

It is still another object of the invention to devise means for indicating when a plug has arrived at a predetermined point within the casing of an oil well, or the like.

Other objects and advantages reside in certain novel features of the apparatus, as will be apparent from the following description taken in connection with the accompanying drawings, in which:

Fig. 1 is a vertical cross-sectional view of the portion of a casing with a cementing plug therein, the cementing plug having means thereon constructed in accordance with the present invention for use in determining the position of the plug.

Fig. 2 is a vertical cross-sectional view of a portion of casing and with an ordinary cementing plug therein, the casing being provided with means constructed in accordance with the present invention for indicating when the plug has reached a certain predetermined position in the casing.

Fig. 3 is a vertical cross-sectional view of the upper portion of a plug similar to that illustrated in Fig. 1, but with a modified form of sounding or vibrating device.

Fig. 4 is a plan view of the plug shown in Fig. 3.

Fig. 5 is a side view of the top of a casing in a well with apparatus constructed in accordance with the present invention secured thereto, together with a showing of the associated recording apparatus.

Fig. 6 is a plan view of a fragment of tape taken from the recorder of Fig. 5 upon which a record of the passage of one plug has been made.

Fig. 7 is a view similar to that of Fig. 6, but showing the recording of two plugs thereon.

Fig. 8 is a diagrammatic showing of the electrical connections between the detecting and recording apparatus of the invention.

Fig. 9 is a cross-sectional view of a plug with still another kind of sounding device thereon; and

Fig. 10 is a side view of a portion of the apparatus of Fig. 9.

Referring to the drawings in detail, and first to the arrangement of Fig. 1, it will be seen that a portion of a jointed pipe or casing is there illustrated as consisting of two sections or stands of pipe designated 11 and 12, these being joined by a collar 13 of conventional construction. As shown, an annular space is ordinarily present just inside the collar, since the sections 11 and 12 are not in abutting relation.

Within the casing a plug 14 is located. This plug may be of the general type shown in my Patent No. 1,369,891 mentioned above, or it may be of any other suitable known construction. It is preferably provided with a suitable washer or packing element 15, at its upper end. In accordance with the present invention, the ordinary

plug is modified to the extent that it is provided with one or more knockers. These may be mounted on the top of the plug as shown at 16 and 17.

The knockers should be made of metal so as to cause a distinct vibration in the casing when they strike the same. They may be mounted on the plug by means of leaf springs 18 and 19, which are so constructed as to press the knockers against the wall of the casing as the plug moves downwardly therethrough. The springs 18 and 19 may be integral and secured to the plug 14 by means of the bolt and nut 20 and 21, which also secure the washer 15 to the plug.

The arrangement is such that as the plug moves downwardly through the casing the knockers 16 and 17 will strike against the casing and make a noise or vibration therein every time the plug passes a collar 13.

In accordance with the present invention it is proposed to provide means for counting the number of times the knockers strike the casing and in this way determine how many collars or joints the plug has passed through. In this way it is possible to locate the position of the plug at any time without measuring.

Accordingly, the sound or vibration in the casing caused by the knockers 16 and 17 is transmitted to the surface of the well through the casing. It is known that a casing is a good conductor of sound or vibration, and if the knockers are so designed as to strike the casing sharply, no trouble is experienced in detecting the sound and in distinguishing it from other noises or vibrations around the oil well, especially where the detecting apparatus of the present invention is used.

It is known in seismographic geophysical exploration to pick up and record vibrations or sounds from the earth. The detectors of such seismographic apparatus usually consists of a casing which is subjected to the vibration or tremor and a bob weight or inertia element which remains substantially stationary while the casing moves. Relative movement between the casing and weight causes an armature to move with respect to the field piece or core of an electro-magnet and thus the vibrations are transmuted into electrical impulses and cause a current of electricity to flow through the coil of the magnet. This current may be amplified and recorded.

A detector similar to that used in seismographic work may be used in the present invention, but the circuit is preferably modified to some extent.

In Fig. 5 the detector is illustrated at 22 and is shown clamped to the top of the casing by means of a band 23. It will be apparent that the casing of the detector 22 will be vibrated as the casing vibrates in response to the striking of the knockers 16 and 17 at various places down in the well.

As illustrated in Fig. 8, electrical impulses will be set up within a coil 40 in the detector 22 and these may be transmitted through an electrical conductor cable 24 to a recording or indicating box 25.

Now it is known that electrical impulses of comparatively low frequencies, such, for example, as the frequencies which correspond to audible sound, can be filtered to remove all impulses of other frequencies. If, therefore, a suitable filter is provided within the recording apparatus 25, as shown at 41, the recording instrument therein will receive only the impulses caused by the knockers 16 and 17 striking the casing. It is preferable also to provide some electrical amplifying circuit within the recorder 25, and this is shown at 42 in Fig. 8.

The recording apparatus, per se, may consist merely of an electro-magnet 43, the armature 44 of which is connected by link mechanism 45 to a stylus 46 adapted to strike a strip of tape 26 when the electro-magnet 43 is energized.

The recording tape 26 may be so arranged that the tape is moved and a mark made thereon every time the knockers 16 and 17 strike the casing. The mechanism for accomplishing this may be similar to that employed in stock market tickers. On the other hand, the tape may be moved at a constant rate of speed by clockwork. In either case the tape may be marked as shown in Fig. 6, as illustrated at 27, each mark indicating that the knockers 16 and 17 have struck the casing. Thus by counting the dots 27 on the tape the number of stands of casing which have been passed by the plug can be determined.

The arrangement shown in Fig. 1 and described above, is best suited for use where the casing has collars or joints and where there is a space between the bottom of one stand of casing and the top of the adjacent one. It has become common in modern casing methods to weld one stand of pipe to the next without the use of the collar, however, and the apparatus of Fig. 1 could not be successfully used in such a casing, unless the casing were specially prepared, with obstructions or the like, to actuate the knockers.

An arrangement especially suitable for use in welded casing is shown in Fig. 2. It is unnecessary in cementing operations to know the exact position of the cementing plug until, or just before, it reaches the point where it is desired to have it remain stationary. It is possible, therefore, to provide the casing with specially made collars at or near the point where it is desired that the plug shall be brought to rest. Thus, as illustrated in Fig. 2, knockers 28 and 29 are mounted in a special collar 30, rather than on a plug 14. The knockers 28 and 29 are mounted upon levers 31 pivoted to supports 32 integral with the collar 30. The levers have bell crank portions 33 adapted to contact the plug 14 and be depressed thereby into the position shown in Fig. 2 when the plug 14 is in contact therewith. Suitable leaf springs 34 are provided, tending to force the knockers 28 and 29 into contact with the collar. Thus, when the plug 14 passes a collar 30 the knockers 28 and 29 strike the collar and vibrations will be transmitted to the surface of the well just as in the arrangement of Fig. 1.

With the arrangement of Fig. 2 it may be desirable to connect several collars 30 into the casing as it is being made up so that as the plug 14 passes the upper collar a warning vibration will be transmitted to the surface and as it passes the next lower collar or collars, its exact position can be indicated.

An advantage in the arrangement of Fig. 2 over that of Fig. 1, where used in a cementing operation, is that it will be unnecessary to drill up the knockers and springs after the well is cemented and drilling operations in the well are continued.

A particular advantage of the present invention results from the fact that the position of two or more plugs within the casing can be kept track of. One way of accomplishing this is to provide for distinguishing knocks on separate plugs.

e arrangement of Figs. 3 and 4, the knock-
e been so constructed as to cause a double
as the plug there shown passes a collar.
lug, in addition to having knockers 16 and
those shown in Fig. 1, is provided with an
nal pair 35 and 36 mounted upon addi-
springs 37 disposed at 90 degrees relation
espect to the springs 18 and 19.
springs 37 are longer than the springs 18
so that the knockers 35 and 36 strike the
after the knockers 16 and 17 strike the
as the plug moves downwardly in the well.
a double knock is effected, which is readily
ed from the single knock where only the
ers 16 and 17 are fixed to the plug.
vill be apparent therefore that where two
are passing downwardly within a casing,
f which is provided with a single pair of
s, as in the arrangement of Fig. 1, and the
of which is provided with a double pair of
ers, as in the arrangement of Figs. 3 and 4,
ord may be obtained upon the tape 26, as
ated at 47 in Fig. 7, which will show the po-
of both plugs. By counting the double dots
the tape the position of one plug can be de-
ned and by counting the number of single
on the tape, the position on the other plug
e determined.
linarily, where two plugs are being passed
wardly through a casing in a cementing op-
on they remain a constant distance apart,
the casing splits or if mud or fluid cement
aking past one of the plugs they may ap-
ch each other and this will be indicated on
ap
an electrical magnet is used to mark the dots
the tape in response to impulses set up in
letector 22, as illustrated in Fig. 8, it may
times happen that the magnet will be mark-
dot upon the tape as the result of the knock-
n one plug striking the casing at the same
that the knockers on another plug are trans-
ng an impulse. This can ordinarily be
ly detected upon the tape, however, because
mpulses do not remain in exact synchronism.
Figs. 9 and 10, a modified form of sounding
nocking device is illustrated. To the top of
plug 14, a toothed wheel 48 is secured by
s of the leaf spring 49, bolted to the plug by
50. The shaft 51 supporting the wheel 48
les a cam 52 which cooperates with a pin 53
ed by a leaf spring 54, the lower end of which
ited to the plug and the upper end of which
les the knocker 55. The teeth on the wheel
nder the influence of the spring 49, bite into
casing and effectively gear the wheel to the
g so that as the plug goes down the wheel
rotate in proportion to its movement. Thus
arrangement is such that the cam 52 will
e the knocker 55 to strike the casing once
ach rotation of the wheel 48, and the move-
t of the plug can be kept track of, by the
-up apparatus at the surface.

It will be apparent to those skilled in the art that instead of using a recording apparatus which marks the tape 26 in the arrangement of Fig. 5, that the tape may be previously calibrated, say with marks thereon an inch apart which will represent one section or stand of casing, and the arrangement may be such that the tape is advanced this unit distance by the apparatus for each knock made upon the casing as the plug moves.

While only a few embodiments have been shown and described herein, it is obvious that various changes may be made without departing from the spirit of the invention or the scope of the annexed claims.

I claim:

1. The combination with a jointed pipe of a device therein and apparatus for indicating the position of the device in the pipe, said apparatus comprising means for setting up a vibration in said pipe each time said device passes a joint therein, thereby producing a number of successive vibrations and means for detecting and recording the successive vibrations in the pipe to determine and record the number of joints the device has passed at any instant.

2. The combination with the casing of an oil well or the like, of a plug adapted for use in cementing the well, resilient means mounted on the plug, a knocker mounted on said resilient means and adapted to strike the casing.

3. A plug adapted for use in cementing an oil well or the like, said plug having a main body portion, a knocker and resilient means connected to the main body portion and to said knocker to mount the knocker on the plug.

4. In an oil well or the like, the combination with the casing thereof of a knocker mounted on the casing within the well, an object within the casing, means adapted to cause the knocker to strike the casing when said object passes through the casing past the knocker and means at the surface of the well for detecting the position of said object as the result of the knocker striking the casing.

5. In an oil well or the like, a casing, a knocker mounted on the casing within the well, an object in the casing, said knocker having means associated therewith and cooperating with said object to cause the knocker to strike the casing when the object passes through the casing past the knocker.

6. Apparatus adapted for use in the cementing of an oil well or the like, including a plurality of plugs adapted to pass through the casing of the well in succession and a system for indicating the position of more than one of said plugs said system including means cooperating with the plugs and casing for creating vibrations in the casing as the plugs pass certain points therein and means at the surface of the well for indicating said vibrations.

ERLE P. HALLIBURTON.